

DDC FILE COPY

ADA060322

**LEVEL II**

AFML-TR-78-100

2

**BEHAVIOR OF NONMETALLIC MATERIALS IN SHALE  
OIL DERIVED JET FUELS AND IN HIGH AROMATIC  
AND HIGH SULFUR PETROLEUM FUELS**

UNIVERSITY OF DAYTON RESEARCH INSTITUTE  
300 COLLEGE PARK AVENUE  
DAYTON, OHIO 45469

105400

JULY 1978

TECHNICAL REPORT AFML-TR-78-100  
Final Report for Period January 1975 - August 1977

Approved for public release; distribution unlimited.

AIR FORCE MATERIALS LABORATORY  
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES  
AIR FORCE SYSTEMS COMMAND  
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

DDC  
RECEIVED  
OCT 25 1978  
D

78 10 19 047

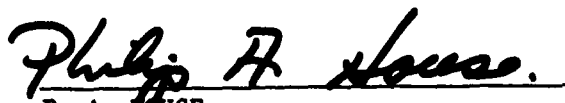
# NOTICE


When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.


Many of the materials tested were not developed or intended by the manufacture for the conditions to which they have been subjected. Any failure or poor performance of a material is, therefore, not necessarily indicative of the utility of the material under less stringent conditions or for other applications.

This report has been reviewed by the Information Office (IO) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

  
P. A. HOUSE  
Project Engineer

  
A. OLEVITCH, Chief  
Nonmetals Engineering Branch  
Systems Support Division

  
W. P. CONRARDY, Chief  
System Support Division

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFML-TR-78-100	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) BEHAVIOR OF NONMETALLIC MATERIALS IN SHALE OIL DERIVED JET FUELS AND IN HIGH AROMATIC AND HIGH SULFUR PETROLEUM FUELS	5. TYPE OF REPORT & PERIOD COVERED Final Report, January 1975 - August 1977	
6. AUTHOR(s) William E. Berner Leonard C. Angello	7. CONTRACT OR GRANT NUMBER(s) F33615-76-C-5034	
8. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Materials Laboratory (MXE) AF Wright Aeronautical Laboratories, AFSC Wright-Patterson Air Force Base, Ohio 45433	9. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Element 62102F Project 2421, Task 242103 Work Unit 24210305	
10. CONTROLLING OFFICE NAME AND ADDRESS Air Force Materials Laboratory (MX) AF Wright Aeronautical Laboratories, AFSC Wright-Patterson Air Force Base, Ohio 45433	11. REPORT DATE July 1978	
12. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 3421 (17) 03	13. NUMBER OF PAGES 75	
	14. SECURITY CLASS. (of this report) Unclassified	
	15. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited. 12 84 p.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Shale Oil                      O-ring                      Fuel Cell Foams Materials Compatibility      Fuel Bladders              Marmon Clamp Seals Jet Fuels                      Fuel Tank Coatings        Compatibility Testing Adhesives                      Bladder Adhesives        Aviation Turbine Fuels Fuel Tank Sealants            Groove Sealants		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The increased pressure on decreasing fuel supplies has prompted the Air Force to examine fuels previously considered unacceptable. Fuels derived from shale oil and fuels high in sulfur and mercaptan sulfur were among those considered unacceptable. The objective of this program was to evaluate nonmetallic aircraft materials relative to increased levels of aromatics, sulfur, and mercaptan sulfur. Aircraft materials that are normally in contact or exposed to fuels were evaluated in ten fuel formulations.		

DD FORM 1 JAN 75 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

205 40 10 19 04

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

19. (Continued)

Fuel Properties  
Fuel Compatibility

LEVEL II

ACCESSION FOR	
DTIC	White Section <input checked="" type="checkbox"/>
DDI	Red Section <input type="checkbox"/>
UNANNOUNCED	<input type="checkbox"/>
JUSTIFICATION	
BY	
DISTRIBUTION/AVAILABILITY CODES	
DR	AVAIL. CODE/REF. SPECIAL
A	

D D C  
RECEIVED  
OCT 25 1978  
REGULATED  
D

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

## FOREWORD

The experimental work reported in this text, dated July 1978, was conducted by the University of Dayton Research Institute, Dayton, Ohio, under USAF Contract F33615-76-C-5034, January 1975 through August 1977. The contract work was performed under Work Unit Number 24210305, Quick Reaction and Evaluation of Materials and Processes for Aerospace Applications, and was administered under the direction of the System Support Division, Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, with Mr. P. A. House (AFML/MXE) as Project Engineer.

The efforts of Mr. J. N. Dues and Mr. A. L. Logue, research materials technicians, were greatly appreciated throughout this program. Their diligent support was extremely beneficial to the successful completion of this program.

## TABLE OF CONTENTS

<u>SECTION</u>		<u>PAGE</u>
I	INTRODUCTION	1
II	DISCUSSION OF THE PROGRAM	3
III	PROCEDURES AND TEST RESULTS	9
	1. Adhesives	9
	2. Fuel Tank Sealants (Curing Type)	16
	3. Fuel Cell Innerliner Materials	22
	4. Bladder Repair Adhesive	28
	5. Groove Sealants (Noncuring Type)	30
	6. Elastomeric Marmon Clamp Seals	34
	7. Elastomeric O-Ring Materials	38
	8. Fuel Cell Baffle Materials	42
	9. Internal Fuel Cell Coatings	43
	10. Evaluation of Non-Conducting Sheet Materials	45
IV	DISCUSSION OF ALL RESULTS	49
	1. Effect of Increased Aromatic Content of JP-4 Type Fuels	49
	2. Effect of Increased Sulfur Level on JP-4 Type Fuels	52
	3. The Effects of Synthetic JP-4 Fuel Derived From Shale Oil Deposits	53
	4. The Effects of Synthetic JET-A Fuel Derived From Shale Oil Deposits	53
V	CONCLUSIONS	56
VI	RECOMMENDATIONS	60
	APPENDIX	62
	REFERENCES	74

## LIST OF ILLUSTRATIONS

<u>FIGURE</u>		<u>PAGE</u>
1	Sketch of Single Lap Shear and Double Lap Shear Specimens	10
2	Typical 180° Peel Type Specimen Used to Determine Adhesion of Curing Type Fuel Tank Sealants	18
3	Typical Fuel Bladder Material in a Permeability Test Cup	26
4	Pressure Rupture Fixture Used to Evaluate the Noncuring Type Fuel Tank Sealants	32

# LIST OF TABLES

<u>TABLE</u>		<u>PAGE</u>
I	Fuel System Description	4
II	Fuel Properties of Shale Oil Derived Fuels vs JP-4 Type Fuels	5
III	Hydrocarbon Type Analysis	7
IV	Schedule of Materials and Test Fuels to Which They Were Exposed	8
V	Compatibility Testing of Double Lap Shear Structural Adhesive Specimens Following Conditioning in Fuel for 7 Days at 140°F	12 & 13
VI	Evaluation of Fuel Tank Sealant Following Conditioning in Fuel for 7 Days at 140°F	19 & 20
VII	Evaluation of Fuel Cell Materials Following Conditioning in Fuel for 7 Days at 140°F	24
VIII	Permeability Test Results of Bladder Materials Following Conditioning in Fuel for 7 Days at 140°F (60°C)	27
IX	Seam Adhesion Test Results Following Conditioning in Fuel for 7 Days at 140°F	29
X	Bladder Adhesive Test Results Following Conditioning in Fuel for 7 Days at 140°F (60°C)	31
XI	Pressure Rupture Test Results for Groove Sealants Following Conditioning in Fuel for 7 Days at 140°F (60°C)	33
XII	Marmon Clamp Material Test Results Following Exposure to Fuel for 7 Days at 140°F (60°C)	36 & 37
XIII	Evaluation of O-Ring Materials Following Conditioning in Fuel for 7 Days at 140°F (60°C)	40 & 41
XIV	Evaluation of Integral Fuel Cell Foam Following Conditioning in Fuel for 7 Days at 140°F (60°C)	44
XV	Pencil Hardness Data on Integral Fuel Tank Coatings Following Conditioning in Fuel for 7 Days at 140°F (60°C)	46
XVI	Evaluation of Sheet Materials Following Conditioning in Fuel for 7 Days at 140°F (60°C)	48



LIST OF TABLES (Continued)

<u>TABLE</u>		<u>PAGE</u>
XVII	Summary of All the Materials/Fuel Compatibility Data	50 & 51

## SECTION I

### INTRODUCTION

Since 1973, the cost and availability of aviation turbine fuels has changed dramatically. Per gallon jet fuel costs have more than tripled. At the same time, both the Air Force and commercial airlines have encountered increased difficulties in obtaining desired quantities of aviation turbine fuels. These developments, coupled with the expectation of deriving future aviation turbine fuels from non-petroleum sources such as oil shale and coal liquid, have encouraged initial examination into the feasibility of broadening current jet fuel specification limits.

As a means of attaining a data base regarding the effect that broadened jet fuel specifications may have on aircraft materials compatibility, a large materials evaluation program was conducted by the Air Force Materials Laboratory (AFML) and the Air Force Aero Propulsion Laboratory (AFAPL). The specific purpose of this program was to determine the effect that increased specification levels of mercaptan sulfur, total sulfur, and aromatic content would have on nonmetallic aircraft materials which contact the fuel in a modern aircraft system.

In this study, four levels of aromatic content and two levels each of mercaptan sulfur and total sulfur were evaluated. These levels included the 10%, 25%, 35%, and 45% by volume levels of aromatic content; the 0.001% and 0.003% by weight levels of mercaptan sulfur; and the 0.1% and 1.0% by weight levels of total sulfur. Current JP-4 specification limits for aromatic content, mercaptan sulfur, and total sulfur are 25%, 0.001%, and 0.4%, respectively.

Also evaluated in this study were two oil shale derived jet fuels. One of these fuels conformed to the JP-4 specification with only minor exceptions. The other conformed most closely to the JP-8 or Jet A fuel specification with several exceptions. A more detailed discussion of these fuels is included in Section II and in the Appendix which discusses the history of JP type fuels and fuel availability vs fuel properties.

The nonmetallic aircraft materials evaluated in this program included structural adhesives, fuel tank sealants, fuel bladder materials, bladder repair adhesives, groove sealants, elastomeric o-ring materials, elastomeric Marmon clamp seals, fuel tank coatings, fuel tank foams, and electrical insulating sheet stock. Although the present program did not evaluate every manufactured material within each of the material categories listed above, the program did attempt to treat each generically different material within a particular material category. For example, there are many structural adhesives used in current aircraft systems. This program evaluated five structural adhesives as being different yet typically used. A more detailed description of the specific materials evaluated is included in Section III.

## SECTION II

### DISCUSSION OF THE PROGRAM

As stated in the introduction, the purpose of this study is to determine the effect that certain jet fuel specification changes may have on aircraft materials compatibility. The particular specification changes examined in this study pertain to the levels of mercaptan sulfur, total sulfur, and aromatic content allowable in JP-4 type fuels. As a means of evaluating these changes, eight JP-4 type test fuels were prepared. These fuels are described in Table I as fuel systems I through VIII. These fuel systems were contrived by doping a baseline JP-4 type fuel with appropriate amounts of tertiary butyl mercaptan, tertiary butyl disulfide, and xylene to formulate fuels with the desired levels of mercaptan sulfur, total sulfur, and aromatic content.

As noted earlier, two levels each of mercaptan sulfur and total sulfur were evaluated. The lower levels of mercaptan and total sulfur evaluated in the study were 0.001 weight percent and 0.1 weight percent, respectively. Fuel systems I, III, V, and VII contain these levels of sulfur at the 10%, 25%, 35%, and 45% levels of aromatic content by volume, respectively. Similarly, fuel systems II, IV, VI, and VIII, doped with the higher levels of sulfur (.003 wt% mercaptan and 1.0 wt% total sulfur), contain aromatic contents of 10%, 25%, 35%, and 45% by volume, respectively.

Also briefly described in Table I as fuel systems IX and X are the respective JP-4 and JET-A shale oil derived fuels. As noted earlier, neither the shale oil JP-4 nor the shale oil JET-A completely meet specifications. Table II compares the properties of these shale derived fuels

TABLE I  
FUEL SYSTEM DESCRIPTION

System

- I Base JP-4, 0.001% mercaptan sulfur, 0.1% total sulfur, 10% aromatics (Base Fuel System).
- II Base JP-4, 0.003% mercaptan sulfur, 1.0% total sulfur, 10% aromatics (Base Fuel System/High Sulfur).
- III Base JP-4, 0.001% mercaptan sulfur, 0.1% total sulfur, 25% aromatics (25% Fuel System).
- IV Base JP-4, 0.003% mercaptan sulfur, 1% total sulfur, 25% aromatics (25% Fuel System/High Sulfur).
- V Base JP-4, 0.001% mercaptan sulfur, 0.1% total sulfur, 35% aromatics (35% Fuel System).
- VI Base JP-4, 0.003% mercaptan sulfur, 1.0% total sulfur, 35% aromatics (35% Fuel System/High Sulfur).
- VII Base JP-4, 0.001% mercaptan sulfur, 0.1% total sulfur, 45% aromatics (45% Fuel System).
- VIII Base JP-4, 0.003% mercaptan sulfur, 0.1% total sulfur, 45% aromatics (45% Fuel System/High Sulfur).
- IX Shale Oil JP-4, trace mercaptan sulfur, 0.03 total sulfur, 10% aromatics, 250 ppm total nitrogen.
- X Shale Oil JET-A, trace mercaptan sulfur, 0.02 total sulfur, 25% aromatics, 460 ppm total nitrogen.

TABLE II

## FUEL PROPERTIES OF SHALE OIL DERIVED FUELS VS JP-4 TYPE FUELS

Test Description	Method	JP-4 Type Fuels			JP-8 Type Fuels		
		JP-4 Base Line	Synthetic JP-4 Shale Oil	Typical Petroleum	Spec Limit	Synthetic JP-4 Shale Oil	Typical Petroleum
Aromatics (Vol %)	D1319	9.1	10.5	10.9	25.0	25.8	14.4
Olefins (Vol %)	D1319	1.3	0.6	0.8	5.0	0.5	1.1
Sulfur, Total (Wt%)	D1266/D2622	0.041	0.02	0.05	0.4	0.03	0.07
Sulfur, Mercaptan (Wt%)	D1219	0.0004		0.0004	0.001		
Nitrogen, Total (ppm)			250	<10		460	<10
Distillation, IBP (°F)	D86	142.	158.	141.		342.	332.
10% Rec (°F)	D86	208.	236.	211.	290.	376.	365.
20% Rec (°F)	D86	226.	256.	233.	370.	390.	379.
50% Rec (°F)	D86	290.	294.	295.		426.	418.
90% Rec (°F)	D86	436.	370.	403.		492.	484.
Final BP (°F)	D86	474.	426.	457.		514.	522.
Gravity °API (60°F)	D287	55.8	56.8	53.9	45-57	44.4	43.4
Vapor Pressure (Reid, lb)	D323/D2551	2.4	2.1	2.6	2.0-3.0		
Flashpoint (°F)	D97						
Freezing Point (°F)	D2386	B-72	B-72	-81	-72max	140.	128
Smoke Point (mm)	D1322		28.5	28.1		A-30	-58 max.
Coker ΔP (mmHg)	D3241		0.0	1.0	25.0	20.	26.0
Coker Tube Color Code			4+(475°F)	1 (500)	3 (500°F)	30.	25.0
Existant Gum (mg/100ml)	D381	1.4	5.8	0.6	7.0	144.2	0.8
Particulates (mg/Liter)	D2276		17.8	0.4	1.0	1.8	0.5
WSIM (min)	D2250		44.	90.	70.	10.	85
Filtration Time (minutes)	D2276		30.+	5.0	15.0	30.+	
Net Heat of Comb (Btu/lbm)	D240	18811	18597	18729	18400	18484	18595
Aniline Gravity Prod	D1405	7896	7753	7121	5250.	6305	6445

(synthetic JP-4 and synthetic JET-A) with those of the specification limits and those of typical petroleum derived fuels. Specifically, thermal stability and particulates were not met by the shale oil JP-4 and thermal stability, particulates, freeze point, gum content, smoke point, and aromatic content were not met by the shale oil JET-A.

The major difference, however, between the shale oil derived fuel used in this study and those derived from petroleum is the extremely high nitrogen content of the shale oil fuels. As shown in Table II, the nitrogen content of typical petroleum jet fuels is less than 10 parts per million (ppm) whereas the shale oil JP-4 and JET-A fuels contain nitrogen contents of 250 and 460 ppm, respectively.

Another major difference among the fuels evaluated on this study is illustrated in Table III. Table III is a comparison of the hydrocarbon type analysis of the baseline JP-4 fuel, the xylene blending stock, fuel system III (25% blend), the shale oil JP-4, and the shale oil JET-A. This analysis illustrates the basic difference between types of aromatic found in JP-4 type fuels and those found in JP-8 type fuels. As seen in Table III, the average carbon number of the JP-4 type fuels (either petroleum or shale oil) is between 8 and 9. This is characteristic of aromatics having the highest solvent power. The average carbon number of 11 for the JET-A type fuels, on the other hand, is characteristic of aromatics with moderate solvent power. The effect of these fuel characteristics on the results of this study are discussed more fully in Sections III and IV.

Not all of the materials tested in this program were exposed to all ten fuels. A schedule of the materials and the fuels is listed in Table IV. The o-ring materials were evaluated in all ten fuels.

TABLE III  
HYDROCARBON TYPE ANALYSIS

COMPOUND TYPE	BASELINE JP-4 (Vol. %)	XYLENE BLENDING STOCK (Vol. %)	FUEL SYSTEM III (25% BLEND) (Vol. %)	SHALE OIL JP-4 (Vol. %)	SHALE OIL JP-8 (Wt. %)
Paraffins	63.8	0.6	52.7	66.5	50.7
Monocycloparaffins	21.8	-	17.6	18.1	17.6
Dicycloparaffins	5.5	-	4.5	2.4	3.0
Alkylbenzenes	7.7	99.4	24.5	11.5	17.7
Indanes & Tetralins	1.2	-	0.7	1.5	9.3
Naphthalines	-	-	-	<.17	1.1
<u>AVERAGE CARBON NUMBER</u>					
Paraffins	9.1	8.5	9.1	8.9	12
Alkylbenzenes	8.8	8.5	8.5	8.6	11
Indones & Tetralins	-	-	-		12



TABLE IV  
SCHEDULE OF MATERIALS AND TEST FUELS  
TO WHICH THEY WERE EXPOSED

<u>Material Description</u>	<u>Fuel</u>									
	<u>I</u>	<u>II</u>	<u>III</u>	<u>IV</u>	<u>V</u>	<u>VI</u>	<u>VII</u>	<u>VIII</u>	<u>IX</u>	<u>X</u>
1. Structural Adhesives	X			X		X		X	X	X
2. Fuel Tank Sealants	X	X		X		X		X	X	X
3. Fuel Cell Innerliner Materials	X			X		X		X	X	X
4. Bladder Repair Adhesives	X			X		X		X	X	X
5. Groove Injection Sealants	X	X		X		X		X	X	X
6. O-Ring Materials	X	X	X	X	X	X	X	X	X	X
7. Marmon Clamp Seal Materials	X			X		X		X	X	X
8. Electrical Sheet Materials	X			X		X		X	X	X
9. Fuel Tank Coatings	X			X		X		X	X	X
10. Fuel Cell Foams	X			X		X		X	X	X

### SECTION III

#### PROCEDURES AND TEST RESULTS

This section of the report discusses the materials evaluation techniques used for each material to determine fuel compatibility. The materials are identified and the test technique specified. The fuels to which each specific material were exposed are also identified. The test results obtained on each material are discussed in detail. Each type of nonmetallic material is discussed separately, for example, the adhesives are discussed separately from fuel tank sealant materials.

##### 1. Adhesives

The type of adhesives evaluated in this program were structural adhesives used on current aircraft systems. They were evaluated by observing their performance in a lap shear type mode following conditioning in jet fuels and synthetic jet fuels. To evaluate the lap shear of the adhesive systems, test specimens were fabricated into a double lap shear configuration. This specimen was chosen over the standard single overlap shear specimen because it had been demonstrated that the double lap shear test results are more reproducible with much narrower scatter bands than the single overlap shear specimen. The basic differences between the single overlap shear specimen and the double lap shear specimen are shown in Figure 1.

Specimens were fabricated from blanks obtained by cutting them from a prepared panel. A total of six panels were used in this program and specimens from each panel were randomly selected to fill the necessary groups of specimens for each exposure condition. At least one specimen



**SINGLE LAP SHEAR  
0.063 ADHERENDS**



**DOUBLE LAP SHEAR  
0.063 ADHERENDS**

**Figure 1 Sketch of Single Lap Shear and Double Lap Shear Specimens**

from each panel was selected to be tested as a control to insure uniformity among test panels. The adherend panels were 2024T-3 aluminum and were carefully prepared. Each panel was wiped with Methyl Ethyl Ketone and then washed with a nonchlorinated alkaline cleaner (Alconox). After being dried with a heat gun, the panels were vapor degreased in trichloroethylene for 5 to 10 minutes. Following cooling to room temperature (RT), they were etched in a sulfuric acid, sodium dichromate acid bath at 140°F (60°C) for 10 minutes. The acid etch solution was 30 parts distilled water, 10 parts sulfuric acid, and 1 part sodium dichromate. After etching, the panels were rinsed in distilled water and then air dried with a heat gun. The adhesive was then applied to the panels and followed by a heat and pressure cure as specified by each manufacturer.

The compatibility of the structural adhesives with jet fuels was determined by evaluating them following conditioning in fuels I, IV, VI, VIII, IX, and X for seven days at 140°F (60°C).

Following the fuel exposure, the test specimens were allowed to cool to RT and tested for lap shear strength at RT. The lap shear data for all five adhesive systems are shown in Table V and discussed in the following paragraphs.

a. EC-2216

EC-2216 is a room temperature curing epoxy-polyamide structural adhesive manufactured by 3M Company. The initial test results have shown the EC-2216 control samples had an ultimate lap shear strength of 1600 psi. Following fuel aging, the adhesive degraded severely in almost all the fuels. Initially, the fuel exposures were conducted using xylene as the aromatic constituent of the fuels. Later in the program the

TABLE V

COMPATIBILITY TESTING OF DOUBLE LAP SHEAR STRUCTURAL ADHESIVE  
SPECIMENS FOLLOWING CONDITIONING IN FUEL FOR 7 DAYS AT 140°F

MATERIAL.	FUEL	ULTIMATE STRENGTH		FAILURE MODE (% Coh)
		(psi)	(MPa)	
EC-2216	None (controls)	1600	11.0	
	Base JP-4, .1% sulfur	1710	11.9	40
	25% arom. <sup>+</sup> , 1% sulfur	1040*	7.2	15
	35% arom. <sup>+</sup> , 1% sulfur	**	**	
	45% arom. <sup>+</sup> , 1% sulfur	**	**	
	Synthetic JP-4	1310	9.0	35
	Synthetic JET-A	1030	7.1	10
FM-47	None (Controls)	4250	29.3	100
	Base JP-4, .1% sulfur	3660	25.2	100
	25% arom. <sup>+</sup> , 1% sulfur	3490	24.1	100
	35% arom. <sup>+</sup> , 1% sulfur	3630	25.0	100
	45% arom. <sup>+</sup> , 1% sulfur	3660	25.2	95
	Synthetic JP-4	3770	26.0	85
	Synthetic JET-A	4320	29.8	75
PL-729-3	None (controls)	3790	26.1	100
	Base JP-4, .1% sulfur	3690	25.4	100
	25% arom. <sup>+</sup> , 1% sulfur	3680	25.4	100
	35% arom. <sup>+</sup> , 1% sulfur	3460	23.9	100
	45% arom. <sup>+</sup> , 1% sulfur	3390	23.4	100
	Synthetic JP-4	3620	25.0	100
	Synthetic JET-A	3670	25.3	100

\* Average of two specimens - one specimen broke while loading into grips

\*\* Not able to test - specimens fell apart

+ Aromatic - toluene

± Aromatic - Xylene

TABLE V (Continued)

<u>MATERIAL</u>	<u>FUEL</u>	<u>ULTIMATE STRENGTH</u>		<u>FAILURE MODE</u> (% Coh)
		(psi)	(MPa)	
AF-126	None (controls)	3730	25.7	100
	Base JP-4, .1% sulfur	4220*	29.1	75
	25% arom. <sup>+</sup> , 1% sulfur	4260	29.4	85
	35% arom. <sup>+</sup> , 1% sulfur	4070	28.1	95
	45% arom. <sup>+</sup> , 1% sulfur	3950	27.2	100
	Synthetic JP-4	3920	27.0	100
	Synthetic JET-A	3730	25.7	100
828/DTA	None (controls)	1120	7.7	0
	Base JP-4, .1% sulfur	2200	15.2	0
	25% arom. <sup>+</sup> , 1% sulfur	2730	18.8	0
	35% arom. <sup>+</sup> , 1% sulfur	1750	12.1	0
	45% arom. <sup>+</sup> , 1% sulfur	1590	11.0	0
	Synthetic JP-4	2480	17.1	0
	Synthetic JET-A	2610*	1.5	0

\* Average of two specimens - the adherend of the third specimen failed prior to the adhesive bond

\* Average of two specimens

<sup>+</sup> Aromatic - Xylene

aromatic constituent was changed from xylene to toluene and the tests were repeated. The EC-2216 was similarly affected by both the xylene and toluene fuels. Only the samples exposed to the toluene fuels are shown in Table V. EC-2216 does not appear to be affected by 0.1% sulfur in Base JP-4 and maintained a reasonably high strength in Synthetic JP-4. Increasing the aromatic and sulfur content, however, degraded the performance of the adhesive. It also lost considerable strength after exposure to Synthetic JET-A. At the 35% aromatic level and above, the specimen fell apart and could not be tested. Partial adhesive type failures were observed on many of the specimens tested.

b. FM-47

FM-47, a vinyl phenolic, is a two-part 350°F (177°C) curing structural film adhesive manufactured by American Cynamid. Double lap shear test results on control samples have shown that FM-47 has an ultimate shear strength of 4250 psi ( $29.3 \times 10^6$  MPa).

Following exposure to the high aromatic and high sulfur fuels, the shear strength was approximately 15% lower than the controls. Similar results were obtained after exposure to Base JP-4/1% sulfur and Synthetic JP-4. Following exposure to Synthetic JET-A, the shear strength slightly increased. A tendency toward adhesive type failures was observed following aging in both synthetic fuels.

c. PL-729-3

PL-729-3 is a modified high temperature epoxy, 350°F (177°C) curing film structural adhesive manufactured by B. F. Goodrich. Control double lap shear specimens had a shear strength of 3790 psi ( $26.1 \times 10^6$  MPa). Following fuel aging, the PL-729-3 adhesive maintained a high shear strength

in all fuel systems. Only slight decreases in strength were observed following exposure to the 35% and 45% aromatic fuels. The aromatic constituent in the fuel was xylene. No change in shear strength was observed following exposure to the two synthetic fuels.

d. AF-126

AF-126 is a nitrile modified epoxy, 250°F (121°C) curing structural film adhesive manufactured by 3M Company. Double lap shear specimens used as controls developed a shear strength of 3730 psi (25.7 x 10<sup>6</sup> MPa). Exposures of this adhesive system to five of the six fuel systems showed an increase in shear strength over the control samples. In Synthetic JET-A, the shear strength was exactly the same as the control samples. Some adhesive type failures were observed on samples that were exposed to the higher aromatic fuels. Although decreasing shear strength was recorded as the aromatic level increased, the amount of decrease was within the margin of error for this type of specimen and was considered negligible.

e. Epon 828/Dimethyltriamine (828/DTA)

The Epon 828/DTA is an unmodified epoxy cured with dimethyltriamine (DTA) and is a room temperature curing adhesive made by Hysol Division of Dexter Corporation. Control samples of 828/DTA had a double lap shear strength of 1100 psi (7.6 x 10<sup>6</sup> MPa). The adhesive system showed a sharp increase in strength following exposure to fuel soaking. This could have been caused by the adhesive undergoing a post cure during the fuel soak at 140°F (60°C). The strength increase was highest following exposure to the 25% aromatic fuel system and to Synthetic JET-A. The strength decreased sharply with aromatic contents above 25% in the fuel. All of the



828/DTA samples prepared failed adhesively from the adherend. These data would indicate poor adhesive bonding properties of the adhesives to the substrate or an alternate surface preparation was necessary.

## 2. Fuel Tank Sealants (Curing Type)

Elastomeric sealing materials are used extensively in modern weapons systems. A primary use of a sealant material is in integral fuel tanks and is designed to last the life of the aircraft. Several classes, types, and compounds are used in today's systems and these have several temperature ranges. Four sealant materials were selected for evaluation in this fuel compatibility program. The material selections were based on compounding and temperature usage range. All of the sealants evaluated in this program were polysulfide-type, two component systems currently in use within Air Force systems.

In the initial portion of the evaluation, the four sealant materials were exposed to fuels I, II, IV, VI, VIII, IX, and X. The aromatic constituent in the initial fuel exposures was xylene. Xylene is commonly used in jet fuels and was used as the aromatic constituent of the test fuels because it was readily available. Typical fuel tank sealant test fuels, however, specify toluene as the aromatic constituent. In this portion of the program, both the xylene and toluene constituents were used.

The fuel compatibility on the four fuel tank sealant materials was determined by conducting an adhesion test following the fuel exposure. The fuel exposure on all sealants was seven days at 140°F (60°C). To determine the adhesion of a sealant-type material to a particular

substrate, 180°F peel specimens were prepared. These samples were prepared according to military specifications and the specimens conditioned in the fuel for seven days at 140°F (60°C) in a closed glass container. At the end of the fuel exposure, the specimens were removed from the oven and allowed to cool for 24 hours in fresh fuel prior to testing for peel strength. A typical peel type specimen is shown in Figure 2.

The results of the adhesion tests on fuel tank sealants are shown in Table VI and discussed in the following paragraphs.

a. PS-890 B-2 (Mil-S-8802)

The Pro Seal 890 B-2 sealant was exposed to 14 fuel compositions. The initial seven fuels were the same as those described above. The aromatic constituent in the fuels was xylene. The remaining seven fuels were similar in composition but the aromatic content in the latter seven fuels was toluene. The effect of increasing aromatic constituent in the fuels was evident in both series of tests. The Pro Seal 890 B-2 sealant lost peel strength after exposure to fuels with aromatic contents exceeding 35%. The loss of adhesion of the sealant in the xylene doped fuel was much more severe than was that in the toluene fuels. The Synthetic JP-4 and Synthetic JET-A fuel systems do not appear to affect the adhesion of the sealant. Some loss of adhesion was observed on the sample exposed to Synthetic JP-4 but the second series showed good peel strength and good adhesion.

b. Pro Seal 899 (Mil-S-83430)

Pro Seal 899 is a high temperature (360°F/182°C) polysulfide-type integral fuel tank sealant that is qualified to Mil-S-83430. It was

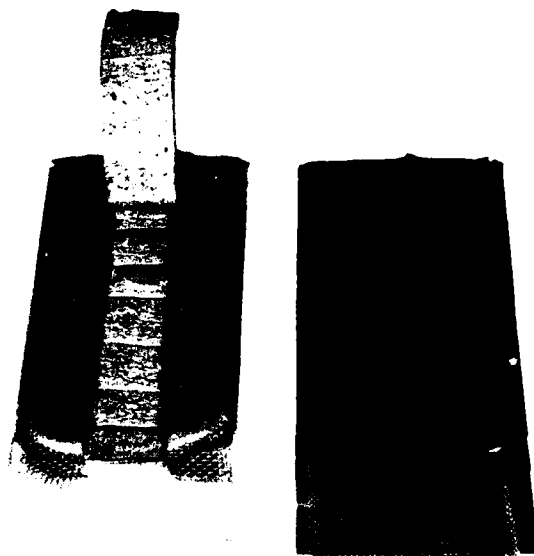


Figure 2 Typical 180° Peel Type Specimen Used to Determine  
Adhesion of Curing Type Fuel Tank Sealants

TABLE VI  
EVALUATION OF FUEL TANK SEALANT FOLLOWING CONDITIONING  
IN FUEL FOR 7 DAYS AT 140°F

<u>MATERIAL</u>	<u>FUEL</u>	<u>LOAD (LBS/INCH)</u>	<u>LOAD NEWTONS/METER</u>	<u>FAILURE MODE (% Coh)</u>
PS 890 B-2	Base JP-4, .1% sulfur	30.5	5341.47	100
	Base JP-4, 1% sulfur	30.5	5341.47	100
	25% arom. <sup>+</sup> , 1% sulfur	26.0	4553.38	100
	35% arom. <sup>+</sup> , 1% sulfur	8.5	1488.61	5
	45% arom. <sup>+</sup> , 1% sulfur	8.0	1401.04	5
	Synthetic JP-4	20.5	3572.65	60
	Synthetic JET-A	29.5	5166.34	100
PS 890 B-2	Base JP-4, .1% sulfur	29.0	5078.77	100
	Base JP-4, 1% sulfur	28.0	4903.64	100
	25% arom. <sup>+</sup> , 1% sulfur	27.0	4728.51	100
	35% arom. <sup>+</sup> , 1% sulfur	23.5	4115.56	100
	45% arom. <sup>+</sup> , 1% sulfur	20.5	3590.17	100
	Synthetic JP-4	28.5	4991.21	100
	Synthetic JET-A	28.5	4991.21	100
PS 899 B-2	Base JP-4, .1% sulfur	28.5	4991.21	100
	Base JP-4, 1% sulfur	26.5	4640.95	100
	25% arom. <sup>+</sup> , 1% sulfur	25.5	4465.82	100
	35% arom. <sup>+</sup> , 1% sulfur	22.5	3940.43	100
	45% arom. <sup>+</sup> , 1% sulfur	21.0	3677.73	100
	Synthetic JP-4	25.5	4465.82	100
	Synthetic JET-A	30.0	5253.90	100

<sup>+</sup> Xylene

<sup>+</sup> Toluene

TABLE VI (Continued)

<u>MATERIAL</u>	<u>FUEL</u>	<u>LOAD (LBS/INCH)</u>	<u>LOAD NEWTONS/METER</u>	<u>FAILURE MODE (% Coh)</u>
PR-1422	Base JP-4, .1% sulfur	22.5	3940.43	100
	Base JP-4, 1% sulfur	22.5	3940.43	100
	25% arom. <sup>+</sup> , 1% sulfur	22.5	3940.43	100
	35% arom. <sup>+</sup> , 1% sulfur	21.5	3765.30	100
	45% arom. <sup>+</sup> , 1% sulfur	19.5	3415.04	100
	Synthetic JP-4	24.0	4203.12	100
	Synthetic JET-A	22.0	3852.86	100
PR-1221	Base JP-4, .1% sulfur	40.0	7005.20	100
	Base JP-4, 1% sulfur	41.0*	7180.33	100
	25% arom. <sup>+</sup> , 1% sulfur	41.0	7180.33	100
	35% arom. <sup>+</sup> , 1% sulfur	39.5	6917.64	100
	45% arom. <sup>+</sup> , 1% sulfur	34.5	6041.99	100
	Synthetic JP-4	46.0	8055.98	100
	Synthetic JET-A	40.5*	7092.77	100

<sup>+</sup> Xylene

\* The load carrying metal screen failed prior to the sealant failing. In both cases, the metal screen failure occurred in excess of 35 pounds per inch width.

exposed to the seven fuels with toluene as the aromatic constituent in the fuel. The results show that, like the Pro Seal 890 compound, the peel strength decreased with increasing aromatic content. It must be pointed out, however, that none of the exposures caused the sealant to fall below the minimum peel strength requirements of the Mil-S-83430 specification of 20 pounds/inch width and 100% cohesive failures were maintained.

c. PR-1422 (Mil-S-8802)

Products Research and Chemical Corporation PR-1422 is a polysulfide-type integral fuel tank sealant qualified to Mil-S-8802D and is suitable for use up to 250°F (121°C). The PR-1422 has a different curing system than does the previously discussed materials. The sealant was exposed to the fuels containing xylene as the aromatic constituent. The PR-1422 was only slightly affected by the increasing aromatic content of the fuel. The sealant is not affected by the Synthetic JP-4 and Synthetic JET-A exposures. The specification requirements for peel strength in the Mil-S-8802 specification are a minimum of 20 pounds/inch width and only after exposure to the 45% aromatic level does the sealant fail to meet the specification requirements.

d. PR-1221 (Mil-S-7502)

Products Research and Chemical Corporation PR-1221 sealant is a two-part polysulfide integral fuel tank sealant that has been used on many older aircraft, some of which are still active. The maximum temperature of this sealant is limited to 225°F (107°C). The sealant is qualified to Mil-S-7502. This sealant has the highest peel strength of all the sealants tested and shows some loss of peel strength due to increasing aromatic

content. However, even at its lowest peel strength, it far surpassed the minimum specification requirements of 20 pounds/inch width. The PR-1221 also had very high peel strength in the two synthetic fuels.

### 3. Fuel Cell Innerliner Materials

Several fuel cell bladder materials were evaluated following conditioning in six different fuels. The materials included:

1. Buna N Bladder - Goodyear 51956  
- Self Sealing
2. Urethane Bladder - Goodyear 80C29  
- Self Sealing
3. Buna N Innerliner - Goodyear FT-99 (Nylon fabric reinforcement)
4. Pliocel - Nylon

To determine the material compatibility of these innerliner materials with the six fuel compositions, each material was evaluated for ultimate tensile strength, elongation, hardness, swell, seam adhesion, and permeability. The six fuels to which the materials were exposed included fuels I, IV, VI, VIII, IX, and X.

The four materials selected were representative of fuel cell bladder materials currently in use. Goodyear 51956 was a Buna N innerliner used for bladder and self-sealing cells. The material evaluated was 0.032 inches thick and had a fuel barrier. FT-99 was a fabric innerliner material for bladder cells only. It was 0.010 inches thick and also had the fuel barrier. The Goodyear 80C29 was a polyurethane innerliner that may be used for bladder and self-sealing fuel tanks. It was 0.014 inches thick and had a fuel barrier. The 80C29 and the Pliocel did not have a seam so no seam adhesion tests were conducted on those materials. The FT-99 and the 51956 materials have 1-1/4 inch lap seams.

The physical property tests were only conducted on two materials, the 51956 and the 80C29. These were conditioned for seven days at 140°F (60°C) in each of the previously mentioned six fuels. Following conditioning, the ultimate tensile strength, elongation, hardness, and volume change were determined. Control samples were also tested to establish baseline properties. The results of these tests are shown in Table VII.

a. Tensile Strength, Elongation, and Volume Change

Slight decreases in ultimate tensile strength, elongation, and hardness were observed on the Buna N 51956 material as the aromatic constituent in the fuel increased. The aromatic constituent in these fuels was xylene. In Synthetic JP-4 the tensile strength, elongation, and hardness did not change from the controls. A slight shrinkage was observed in both the Base JP-4 and the Synthetic JP-4. In Synthetic JET-A, the same was true except the test samples indicated a slight swell. A steady increase in swell was observed with increasing aromatic content.

The urethane 80C29 material showed a sharp drop in tensile strength, a slight drop in elongation, a sharp increase in hardness, and a 9% volume swell following exposure to the Base JP-4 with 0.1% sulfur. In fuels with 25%, 35%, and 45% aromatic contents, the tensile strength remained the same but the elongation increased and hardness decreased. The volume swell also increased reaching a maximum of 21.9%. In Synthetic JP-4 and Synthetic JET-A, the tensile strength dropped sharply, the elongation dropped slightly, and the hardness increased slightly. The volume changes were 8.4% and 12.8%, respectively.

In general, the urethane bladder is adversely affected by all fuel systems, The largest decrease in tensile strength and elongation



TABLE VII  
EVALUATION OF FUEL CELL MATERIALS FOLLOWING  
CONDITIONING IN FUEL FOR 7 DAYS AT 140°F

<u>MATERIAL</u>	<u>FUEL</u>	<u>TENSILE STRENGTH (psi)</u>	<u>TENSILE STRENGTH (MPa)</u>	<u>ELONG. (%)</u>	<u>HARDNESS (Shore A<sub>2</sub>)</u>	<u>SWELL (%)</u>
Buna N Bladder Goodyear 51956	None (controls)	1750	12.1	411	57	
	Base JP-4, .1% sulfur	1790	12.3	440	50	-2.8
	25% arom., 1% sulfur	1540	10.6	435	57	4.6
	35% arom., 1% sulfur	1380	9.5	410	57	10.1
	45% arom., 1% sulfur	1190	8.2	360	55	16.1
	Synthetic JP-4	1860	12.8	455	61	-1.6
	Synthetic JET-A	1800	12.4	470	59	1.4
Urethane Bladder 80C29	None (controls)	4480	30.9	345	78	
	Base JP-4, .1% sulfur	2770	19.1	320	85	8.8
	25% arom., 1% sulfur	3410	23.5	370	87	13.9
	35% arom., 1% sulfur	3350	23.1	390	86	18.2
	45% arom., 1% sulfur	3250	22.4	420	80	21.9
	Synthetic JP-4	3480	24.0	330	83	8.4
	Synthetic JET-A	2290	15.8	320	87	12.8

Aromatic - Xylene

occurred following aging in Synthetic JET-A. The effects of the fuel on the Buna N innerliner were not as severe as with the urethane and the Buna N does not appear to be affected by the synthetic fuels.

b. Permeability

Permeability testing was conducted on four fuel cell bladder materials. The same six fuels used in the physical property tests were also used in the permeability tests. The four materials evaluated were:

1. Goodyear Pliocel - Nylon
2. Goodyear 80C29 - Urethane
3. Goodyear 51956 - Buna N (included fuel barrier)
4. Goodyear FT-99 - Buna N (no fuel barrier)

The aromatic constituent in the fuels used in these tests was toluene. The permeability tests were conducted according to the procedure of Mil-T-6396C, paragraph 4.6.12. Figure 3 shows a typical bladder material in a permeability test cup. The requirements of this specification state that the diffusion rate shall be less than 0.025 fluid ounces per square foot per 24 hours. All of the candidate materials except the Buna N innerliner passed the minimum requirements of the specification. The Buna N FT-99 passed following conditioning in fuels VI, VII, and X but failed to meet the requirements in the other three fuels. The test results are shown in Table VIII.

In general, all the materials showed a lower diffusion rate in the Synthetic JET-A than they did in Synthetic JP-4. In all cases, the diffusion rate in Synthetic JET-A was the lowest for all fuels tested.

c. Seam Adhesion

A seam adhesion test was conducted on the Buna N innerliner FT-99 following fuel soaking the six fuels for seven days at 140°F (60°C).

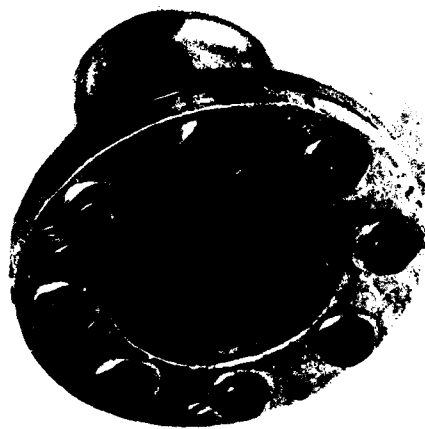


Figure 3 Typical Fuel Bladder Material in a  
Permeability Test Cup

TABLE VIII

PERMEABILITY TEST RESULTS OF BLADDER MATERIALS  
FOLLOWING CONDITIONING IN FUEL FOR 7 DAYS AT 140°F (60°C)

<u>MATERIAL</u>	<u>FUEL</u>	<u>DIFFUSION RATE</u>	
		<u>FL OZ/SQ FT/24 HRS</u>	<u>ML/CM<sup>2</sup>/24 HRS</u>
Buna N Inner-liner (FT-99)	Base JP-4, .1% sulfur	.0758	.1819
	25% arom., 1% sulfur	.0232	.0557
	35% arom., 1% sulfur	.0157	.0377
	45% arom., 1% sulfur	.0129	.0310
	Synthetic JP-4	.1041	.2498
	Synthetic JET-A	.0049	.0118
Buna N 51956	Base JP-4, .1% sulfur	.0030	.0072
	25% arom., 1% sulfur	.0015	.0036
	35% arom., 1% sulfur	.0028	.0067
	45% arom., 1% sulfur	.0033	.0079
	Synthetic JP-4	.0031	.0074
	Synthetic JET-A	.0019	.0046
Pliocel	Base JP-4, .1% sulfur	.0031	.0074
	25% arom., 1% sulfur	.0016	.0038
	35% arom., 1% sulfur	.0023	.0055
	45% arom., 1% sulfur	.0027	.0065
	Synthetic JP-4	.0069	.0166
	Synthetic JET-A	.0006	.0014
Goodyear 80C29 Urethane	Base JP-4, .1% sulfur	.0012	.0029
	25% arom., 1% sulfur	.0013	.0031
	35% arom., 1% sulfur	.0055	.0132
	45% arom., 1% sulfur	.0045	.0108
	Synthetic JP-4	.0010	.0024
	Synthetic JET-A	.0007	.0017

Aromatic - Toluene

The fuels were the same as those used on the physical property tests and also on the permeability tests. The innerliner material was tested according to Mil-T-6396C, paragraph 4.6.16, and recorded its highest load following conditioning in Base JP-4, 0.1% sulfur. The lowest load was recorded following exposure to Synthetic JET-A. None of the loads were close to passing the minimum requirements of the specification of 6.0 pounds/inch. The test results are shown in Table IX.

#### 4. Bladder Repair Adhesive

Military specification Mil-A-9117 is a specification that covers one-part synthetic elastomeric adhesives used to repair fuel cell bladder materials. The particular adhesive selected for these evaluations was 3M Company EC-678 adhesive. It was evaluated by conducting a strip back peel test following fuel aging. The fuels selected for these tests were the same as those used in evaluating the fuel cell bladder materials, namely fuels I, IV, VI, VIII, IX, and X.

The strip back peel specimens were made by bonding sheets of Buna N innerliner (FT-99) material to each other with the EC-678 adhesive. The specimens were prepared and the tests were performed according to Mil-A-9117, paragraph 4.5, with several substitutions. The six test fuels were substituted for the one in the specification and the adherend used was the Buna N innerliner rather than the standard NRB-H stock used in the specification. The aromatic constituent of the fuels was toluene.

The test results showed that the adhesive remained stronger than the adherends following exposure to all test fuels. The control samples

TABLE IX

SEAM ADHESION TEST RESULTS FOLLOWING  
CONDITIONING IN FUEL FOR 7 DAYS AT 140°F

<u>MATERIAL</u>	<u>FUEL</u>	<u>LOAD</u> <u>(LBS/INCH)</u>	<u>LOAD</u> <u>NEWTONS/METER</u>
Buna N Inner- liner (FT-99)	Base JP-4, .1% sulfur	0.83	145.36
	25% arom., 1% sulfur	0.25	43.78
	35% arom., 1% sulfur	0.20	35.03
	45% arom., 1% sulfur	0.34	59.54
	Synthetic JP-4	0.18	31.52
	Synthetic JET-A	0.10	17.51

Aromatic - Xylene

pulled 3.5 pounds/inch. Following exposure to fuels I, IV, VI, VIII, and IX, the strip back peel strength dropped to less than one pound/inch. In Synthetic JET-A, however, the specimens pulled nearly 3.0 pounds/inch. In all cases, however, the failure of the Buna N adherends occurred prior to any failure of the repair adhesive. The tests are shown in Table X.

#### 5. Groove Sealants (Noncuring Type)

Noncuring groove injection sealants are used to seal wet fuel tanks in many modern aircraft systems. Two sealants were evaluated, PR-703, a polysulfide manufactured by Products Research and Chemical Corporation, and 94-031, a fluorosilicone manufactured by Dow Corning. The sealants were evaluated following conditioning in seven fuel systems. These included systems I, II, IV, VI, VIII, IX, and X. The material evaluations were performed by conducting pressure rupture tests as described in Mil-S-81323, paragraph 4.6.11 (see Figure 4). The seven fuel systems were substituted for the jet reference fluid required by the specification.

The test results shown in Table XI indicated that the control sample of the 94-031 sealant required a higher pressure for blowout than did the PR-703. Both the PR-703 and the 94-031 sealant meet the minimum specification requirements of 12 inches of mercury prior to fuel soaking and 3.5 inches of mercury after fuel soaking. The PR-703 continued to degrade with increasing aromatic content. The 94-031 sealant was not as severely affected by the increasing aromatic content. The results of the samples tested in the Synthetic JP-4 are about the same as for the Base JP-4.

TABLE X

BLADDER ADHESIVE TEST RESULTS FOLLOWING CONDITIONING  
IN FUEL FOR 7 DAYS AT 140°F (60°C)

<u>MATERIAL</u>	<u>FUEL</u>	<u>LOAD (LBS/INCH)</u>	<u>LOAD NEWTONS/METER</u>
EC-678 Adhesive*, Buna N Innerliner Adherends	None (controls)	3.50	612.96
	Base JP-4, .1% sulfur	0.57	45.53
	25% arom., 1% sulfur	0.19	15.76
	35% arom., 1% sulfur	0.16	12.26
	45% arom., 1% sulfur	0.36	28.02
	Synthetic JP-4	0.67	52.54
	Synthetic JET-A	2.99	238.18

Aromatic - Toluene

\* Adhesive not actually tested - failure was between plies of the adherend  
in all specimens.





Figure 4 Pressure Rupture Fixture Used to Evaluate  
the Noncuring Type Fuel Tank Sealants

TABLE XI

PRESSURE RUPTURE TEST RESULTS FOR GROOVE SEALANTS  
 FOLLOWING CONDITIONING IN FUEL FOR 7 DAYS AT 140°F (60°C)

<u>MATERIAL</u>	<u>FUEL</u>	<u>PRESSURE (IN/HG)</u>	<u>PRESSURE (CM HG)</u>
PR-703	None (controls)	14.00	35.56
	Base JP-4, .1% sulfur	11.20	28.45
	Base JP-4, 1% sulfur	10.75	27.30
	25% arom., 1% sulfur	7.65	19.43
	35% arom., 1% sulfur	8.25	20.96
	45% arom., 1% sulfur	6.50	16.51
	Synthetic JP-4	9.65	24.51
	Synthetic JET-A	12.20	30.99
94-031	None (controls)	21.25	53.98
	Base JP-4, .1% sulfur	16.50	41.91
	Base JP-4, 1% sulfur	13.75	34.92
	25% arom., 1% sulfur	11.25	28.58
	35% arom., 1% sulfur	11.80	29.97
	45% arom., 1% sulfur	11.00	27.94
	Synthetic JP-4	15.00	38.10
	Synthetic JET-A	19.25	48.90

Aromatic - Xylene

## 6. Elastomeric Marmon Clamp Seals

Marmon clamps have seen widespread usage throughout modern aircraft systems. Many of these contain elastomeric seals which are exposed to a variety of environments. To evaluate the effect that high sulfur, high mercaptan content, and high aromatic content might have on these seals, typical seal compounds were evaluated. The compounds were:

502-100 - Pacific Molded Products (Mil-R-6855, Class I)

AMS-3227 - Pacific Molded Products

24548-100 - Pacific Molded Products

17466-502 - Kirkhill Rubber Co. (Fabric reinforced)

They were considered by the suppliers as those typically found in aircraft such as the B-52.

To determine the compatibility of the seals in the test fuels, dog-boned tensile samples were cut from the clamp seal. The ultimate tensile strength, elongation, hardness, and volume swell were determined on the seal materials following aging in the various fuels. The fuels used in this portion of the program were fuels I, IV, VI, VIII, IX, and X. In addition, control samples were also tested at room temperature. The aromatic constituent in the fuels used was xylene.

### a. Tensile Strength and Elongation

The test results show that basically the tensile strength of all of the materials tested, except the PMP 24548-100, behave the same in the six fuels. The tensile strength drops slightly when the seal is exposed to any of the test fuels. The PMP 24548-100 samples indicated a sharp decrease in tensile strength when exposed to all of the test fuels.

There was a significant decrease in strength for all the seal materials following aging in fuel VIII (45% aromatics). There does not appear to be any significant change in the results of samples aged in the two synthetic fuels. The complete test results are shown in Table XII.

The elongation of the four test materials varied among the four. The PMP 502-100 material showed an increase in elongation after exposure to all fuels. The highest elongations occurred with the synthetic fuels. PMP 503-162, PMP 24548-100, and Kirkhill 17466 had decreasing elongation with increasing aromatic contents. PMP 24548-100 lost considerable elongation in all fuels. These materials also showed that the elongation in the synthetic fuels was equal or greater than that of the Base JP-4 0.1% sulfur.

b. Hardness

PMP 503-162 did not show any decrease in hardness in any of the fuels. Kirkhill 17466 recorded hardness measurements similar to the PMP 503-162. The PMP 24548-100 hardness data showed that any fuel exposure significantly decreased hardness. PMP 502-100 showed lower hardness values following all fuel exposures with the lowest values occurring with fuels VI and VIII.

c. Volume Swell

The volume swell data on all four materials were similar. Volume swells increased with increasing aromatic content of the fuels. The volume swell of the PMP 24548-100 material was much higher than the others tested. In the synthetic fuels, samples conditioned in Synthetic JP-4 had a lower swell than those exposed to Synthetic JET-A. The volume swells for all four materials ranged from a minimum of 6.6% for the Kirkhill 17466 in fuel I to 158% for PMP 24548-100 in fuel VIII.

TABLE XII  
MARCON CLAMP MATERIAL TEST RESULTS FOLLOWING EXPOSURE  
TO FUEL FOR 7 DAYS AT 140°F (60°C)

<u>MATERIAL</u>	<u>FUEL</u>	<u>TENSILE STRENGTH (psi)</u>	<u>TENSILE STRENGTH (MPa)</u>	<u>ELONG. (%)</u>	<u>HARDNESS (SHORE A<sub>2</sub>)</u>	<u>SWELL (%)</u>
Mil-R-6855 Class I, PMP 502-100	None (controls)	1420	9.8	239	67	
	Base JP-4, .1% sulfur	1250	8.6	283	56	11.5
	25% arom., 1% sulfur	1260	8.7	291	56	23.4
	35% arom., 1% sulfur	1120	7.7	271	45	33.2
	45% arom., 1% sulfur	950	6.6	280	46	42.4
	Synthetic JP-4	1230	8.5	360	51	12.8
	Synthetic JET-A	1220	8.4	400	57	16.1
AMS-3227 PMP 503-162	None (controls)	1320	9.1	579	53	
	Base JP-4, .1% sulfur	1080	7.5	389	59	11.7
	25% arom., 1% sulfur	980	6.8	394	52	21.6
	35% arom., 1% sulfur	970	6.7	386	52	29.0
	45% arom., 1% sulfur	710	4.9	327	52	37.9
	Synthetic JP-4	1210	8.3	437	56	13.4
	Synthetic JET-A	1090	7.5	427	53	16.0
Mil-R-6855 Class I, PMP 24548-100	None (controls)	1810	12.5	278	62	
	Base JP-4, .1% sulfur	410	2.8	158	39	110.4
	25% arom., 1% sulfur	310	2.1	123	46	120.2
	35% arom., 1% sulfur	385	2.7	139	42	156.9
	45% arom., 1% sulfur	275	1.9	112	43	158.9
	Synthetic JP-4	550	3.8	133	40	93.2
	Synthetic JET-A	575	4.0	123	47	106.7

Aromatic - Xylene

TABLE XII(Continued)

<u>MATERIAL</u>	<u>FUEL</u>	<u>TENSILE STRENGTH (psi)</u>	<u>TENSILE STRENGTH (MPa)</u>	<u>ELONG. (%)</u>	<u>HARDNESS (SHORE A<sub>2</sub>)</u>	<u>SWELL (%)</u>
KRC 17466-502 (fabric rein- forced)	None (controls)	840	5.8	341	58	
	Base JP-4, .1% sulfur	590	4.1	355	58	6.6
	25% arom., 1% sulfur	560	3.9	297	57	16.2
	35% arom., 1% sulfur	520	3.6	287	62	22.7
	45% arom., 1% sulfur	495	3.4	226	54	29.7
	Synthetic JP-4	620	4.3	350	60	7.9
	Synthetic JET-A	690	4.8	310	61	10.6

Aromatic - Xylene

## 7. Elastomeric O-Ring Materials

The o-ring materials selected for evaluation in this program have seen wide use throughout all weapons systems. The three o-ring materials selected were a Buna N, a fluoroelastomer, and a fluorosilicone. Two o-ring suppliers provided the test materials. They were:

Buna N - Precision Rubber Co. 7866

Fluoroelastomer - Parker Seal Co. V747

Fluorosilicone - Precision Rubber Co. 11647

The materials selected were qualified to the following military specifications:

Buna N - Mil-P-5315

Fluoroelastomer - Mil-R-83248

Fluorosilicone - Mil-R-25988

The material evaluations were conducted by determining the ultimate tensile strength and elongation, the hardness, and the volume change on premolded o-rings following conditioning in ten fuels. The samples were conditioned in the test fuels for seven days at 140°F (60°C). The fuels used were I, II, III, IV, V, VI, VII, VIII, IX, and X.

### a. Tensile Strength and Elongation

The test results of the Buna N compound, Precision 7866, showed that with increasing aromatic content the ultimate tensile strength decreased. The elongation dropped about 25% in all the doped fuels but remained nearly constant despite the aromatic and sulfur levels. The tensile strength, after exposure to the Synthetic fuels, was the same as that after exposure to Base JP-4.

The fluoroelastomer, Parker V747, was exposed to only six fuel systems. These were fuels I, IV, VI, VIII, IX, and X. The test results showed that the tensile strength and elongation were only slightly affected by the fuel exposures. There was also less of an effect after exposure to Synthetic JET-A than there was in Synthetic JP-4.

The tensile strength and elongation tests of the Precision 11647 fluorosilicone compound were conducted in the fuels containing both toluene and xylene. The initial set of test data obtained in xylene fuels only showed that the compound lost tensile strength and gained elongation following exposure to the Base JP-4 and the high aromatic fuels. In the synthetic fuels, the compound lost tensile strength but the elongation remained about the same. In the second series of tests, the tensile strength of the control samples was lower than the initial series while the elongation was higher. The tensile strength in the second series of tests showed a loss in strength and elongation in all fuels. These results were unlike the initial series in that the elongation also decreased in this series of tests. The compound had the lowest tensile and elongation following conditioning in Synthetic JET-A. The behavior of the compound in Synthetic JP-4 was much better than in the other synthetic. No attempt was made to correlate the results between the two aromatic constituents in the fuels. Only minor changes in tensile strength and elongation were observed with varying sulfur contents. The overall tensile strength of both series of control samples was considered low by about 200-400 (1.4-2.8 MPa). The complete test results are shown in Table XIII.



TABLE XIII  
EVALUATION OF O-RING MATERIALS FOLLOWING CONDITIONING  
IN FUEL FOR 7 DAYS AT 140°F (60°C)

<u>MATERIAL</u>	<u>FUEL</u>	<u>TENSILE STRENGTH (psi)</u>	<u>TENSILE STRENGTH (MPa)</u>	<u>ELONG. (%)</u>	<u>HARDNESS (SHORE A<sub>2</sub>)</u>	<u>SWELL (%)</u>
Precision 7866 Mil-P-5315	None (controls)	1100	7.6	253	75	
	Base JP-4, .1% sulfur	725	5.0	202	62	13.10
	Base JP-4, 1% sulfur	662	4.6	190	65	13.70
	25% arom. <sup>+</sup> , .1% sulfur	494	3.4	183	66	25.70
	25% arom. <sup>+</sup> , 1% sulfur	533	3.7	197	71	26.80
	35% arom. <sup>+</sup> , .1% sulfur	485	3.3	189	60	38.00
	35% arom. <sup>+</sup> , 1% sulfur	458	3.2	190	64	42.20
	45% arom. <sup>+</sup> , .1% sulfur	433	3.0	191	62	53.10
	45% arom. <sup>+</sup> , 1% sulfur	422	2.9	181	63	59.20
	Synthetic JP-4	736	5.1	221	64	13.50
	Synthetic JET-A	723	5.0	221	66	16.30
Precision 7866 Buna N	None (controls)	1160	8.0	280	68	
	Base JP-4, 1% sulfur	855	6.0	180	60	13.67
	Base JP-4, .1% sulfur	930	6.4	190	60	12.33
	25% arom. <sup>+</sup> , 1% sulfur	765	5.3	185	59	28.13
	25% arom. <sup>+</sup> , .1% sulfur	690	4.8	170	57	26.74
	35% arom. <sup>+</sup> , 1% sulfur	660	4.6	180	59	41.90
	35% arom. <sup>+</sup> , .1% sulfur	550	3.8	160	58	39.01
	45% arom. <sup>+</sup> , 1% sulfur	560	3.9	175	59	57.44
	45% arom. <sup>+</sup> , .1% sulfur	475	3.3	155	58	53.89
	Synthetic JP-4	755	5.2	165	59	13.97
	Synthetic JET-A	700	4.8	170	59	16.58

<sup>+</sup> Xylene

<sup>+</sup> Toluene

TABLE XIII(Continued)

<u>MATERIAL</u>	<u>FUEL</u>	<u>TENSILE STRENGTH (psi)</u>	<u>TENSILE STRENGTH (MPa)</u>	<u>ELONG. (%)</u>	<u>HARDNESS (SHORE A<sub>2</sub>)</u>	<u>SWELL (%)</u>
Parker V747-75 Fluoroelastomer	None (controls)	1570	10.8	175	75	
	Base JP-4, .1% sulfur	1440	9.9	180	64	2.37
	25% arom. <sup>+</sup> , 1% sulfur	1320	9.1	165	63	4.81
	35% arom. <sup>+</sup> , 1% sulfur	1440	9.9	175	63	5.54
	45% arom. <sup>+</sup> , 1% sulfur	1380	9.5	175	62	7.54
	Synthetic JP-4	1360	9.4	165	64	2.96
	Synthetic JET-A	1520	10.5	180	64	2.39
Precision 11647 Fluorosilicone	None (controls)	876*	6.0	170	59	
	Base JP-4, 1% sulfur	620	4.3	300	57	9.07
	Base JP-4, .1% sulfur	675	4.7	285	60	8.73
	25% arom. <sup>+</sup> , 1% sulfur	670	4.6	280	55	10.38
	25% arom. <sup>+</sup> , .1% sulfur	605	4.2	255	56	9.72
	35% arom. <sup>+</sup> , 1% sulfur	610	4.2	270	51	10.05
	35% arom. <sup>+</sup> , .1% sulfur	650	4.5	275	56	10.89
	45% arom. <sup>+</sup> , 1% sulfur	690	4.8	300	52	11.05
	45% arom. <sup>+</sup> , .1% sulfur	720	5.0	315	57	11.00
	Synthetic JP-4	570	3.9	170	57	8.28
	Synthetic JET-A	460	3.2	160	57	6.01
Precision 11647	None (controls)	663	4.6	209	74	
	Base JP-4, .1% sulfur	399	2.8	173	70	10.00
	Base JP-4, 1% sulfur	384	2.7	176	72	10.10
	25% arom. <sup>+</sup> , .1% sulfur	436	3.0	186	72	11.10
	25% arom. <sup>+</sup> , 1% sulfur	432	3.0	190	72	13.40
	35% arom. <sup>+</sup> , .1% sulfur	423	2.9	191	68	11.90
	35% arom. <sup>+</sup> , 1% sulfur	454	3.1	186	69	14.60
	45% arom. <sup>+</sup> , .1% sulfur	391	2.7	180	68	12.50
	45% arom. <sup>+</sup> , 1% sulfur	448	3.1	221	70	15.70
	Synthetic JP-4	491	3.4	148	77	9.40
	Synthetic JET-A	353	2.4	101	78	7.10

+ Xylene

+ Toluene

b. Hardness

The hardness test data for the Precision 7866 Buna N compound showed a slight decrease in hardness in all the test fuels but the effect of aromatic and sulfur constituents was insignificant. The Parker V747 compound showed a slight decrease in hardness after exposure to all fuels. The samples showed no change in hardness among the various fuels tested. The Precision 11647 fluorosilicone compound tested showed slight decreases in hardness with increasing aromatic contents. The hardness test results, after exposure to the synthetic fuels, were the same or slightly higher than the hardness of the control samples.

c. Volume Change

The Buna N compound showed an increase in volume swell with increasing aromatic content. The volume swell in the synthetic fuels was the same as that of the Base JP-4 fuel systems. The Parker V747 compound showed increasing volume swell with increasing aromatic content, and the swell in the synthetic compounds was equivalent to that of the Base JP-4 fuel. The Precision 11647 fluorosilicone did not appear sensitive to the increasing aromatic content as did the other compounds. The overall volume change was approximately 9% for all test fuels, except that of the Synthetic JET-A where it dropped to 6%.

8. Fuel Cell Baffle Materials

Two samples of integral fuel tank baffle materials were evaluated for compatibility in six of the test fuels. Both of the samples were reticulated open cell foam supplied by ASD/ENF. One sample was a red polyurethane foam as described in Mil-B-83054A, Type III. The other

was a blue hybrid polyether foam. The compatibility tests were conducted by determining the ultimate tensile strength, elongation, and volume change of samples aged in the six fuels. The six fuels used were fuels I, IV, VI, VIII, IX, and X. The tensile strength and elongation were determined by testing dog-boned shaped samples following conditioning in the test fuels for seven days at 140°F (60°C). The pre-cut tensile strength samples were supplied by ASD/ENF.

The test results of the blue polyether foam showed that the polyether compound lost considerable strength and elongation in all the test fuels. There was no appreciable change in the test results among the six fuels. The red polyurethane had a much higher initial tensile strength and elongation than did the polyether foam. It also showed some degradation in strength and elongation with increasing aromatic fuel content. The minimum strength of the red foam was still more than twice that of the blue foam following fuel exposures. All of the test data are shown in Table XIV.

The volume swell of the red polyurethane foam was much less than that of the blue polyether foam. Both showed a tendency to increase with increasing aromatic content.

#### 9. Internal Fuel Cell Coatings

Two integral fuel cell corrosion prevention coatings were evaluated for fuel compatibility in six of the test fuels. The evaluations were determined by measuring the pencil hardness of the coating following conditioning in the six fuels. The pencil hardness test was performed by determining the hardness of the pencil that would slide across the

TABLE XIV

EVALUATION OF INTEGRAL FUEL CELL FOAM FOLLOWING  
CONDITIONING IN FUEL FOR 7 DAYS AT 140°F (60°C)

<u>MATERIAL</u>	<u>FUEL</u>	<u>TENSILE STRENGTH (psi)</u>	<u>TENSILE STRENGTH (MPa)</u>	<u>ELONG. (%)</u>	<u>SWELL (%)</u>
Blue Foam Hybrid Polyether Run P-418 (I-3)	None (controls)	19.00	.13	195	
	Base JP-4, .1% sulfur	7.10	.05	135	48.50
	25% arom., 1% sulfur	7.80	.05	130	56.80
	35% arom., 1% sulfur	7.40	.05	120	60.70
	45% arom., 1% sulfur	9.10	.06	120	67.90
	Synthetic JP-4	7.40	.05	120	48.10
	Synthetic JET-A	8.60	.06	110	48.50
Red Foam Mil-B-83054A Type III Run 808K (5-1)	None (controls)	28.70	.20	326	
	Base JP-4, .1% sulfur	22.70	.16	275	30.10
	25% arom., 1% sulfur	21.90	.15	310	30.40
	35% arom., 1% sulfur	20.00	.14	290	28.90
	45% arom., 1% sulfur	19.90	.14	240	36.60
	Synthetic JP-4	24.50	.17	280	29.10
	Synthetic JET-A	25.70	.18	285	32.60

Aromatic - Xylene

surface of the coating without cutting it. A sample of each coating was exposed to the six fuels for seven days at 140°F (60°C). The fuels used were test fuels I, IV, VI, VIII, IX, and X and contained an aromatic in the form of xylene. The two coating systems evaluated were a polyurethane coating qualified to Mil-C-27725 and a Buna N coating qualified to Mil-S-4383.

The test results showed the polyurethane coating increased in hardness with increasing aromatic content. The coating also appeared harder following exposure to Synthetic JET-A. The Buna N coating was much softer than the polyurethane coating. It showed a tendency to become slightly softer with increasing aromatic content. In the two synthetic fuels, the coating became much harder in Synthetic JET-A than it did in Synthetic JP-4. The test results are shown in Table XV.

#### 10. Evaluation of Non-Conducting Sheet Materials

Two electrically insulating sheet materials were also evaluated for compatibility with six of the test fuels. These were thin sheets, less than 0.010 inches (0.025 cm). Dog-boned shaped tensile specimens were cut from the sheet stock and tested for tensile strength and elongation following aging in the six fuels. The two sheet materials used were polyethylene and Nylon 101. The six fuels were I, IV, VI, VIII, IX, and X.

The results of the tensile and elongation tests showed that the polyethylene material lost some of its strength and elongation following fuel conditioning. The polyethylene had lower tensile strength and elongation in Synthetic JET-A than it did in Synthetic JP-4. The Nylon

TABLE XV

PENCIL HARDNESS DATA ON INTEGRAL FUEL TANK COATINGS  
 FOLLOWING CONDITIONING IN FUEL FOR 7 DAYS AT 140°F (60°C)

<u>MATERIAL</u>	<u>FUEL</u>	<u>PENCIL HARDNESS</u>
Mil-C-27725	Base JP-4, .1% sulfur	7H
	25% arom., 1% sulfur	5H
	35% arom., 1% sulfur	9H
	45% arom., 1% sulfur	9H
	Synthetic JP-4	7H
	Synthetic JET-A	9H+
Mil-S-4383	Base JP-4, .1% sulfur	5B
	25% arom., 1% sulfur	6B
	35% arom., 1% sulfur	2B
	45% arom., 1% sulfur	6B-
	Synthetic JP-4	5B
	Synthetic JET-A	HB

RANGE OF PENCIL HARDNESS

SOFT    7B-6B-5B-4B-3B-2B-B-HB-F-H-2H-3H-4H-5H-6H-7H-8H-9H    HARD

Aromatic - Xylene

101 material showed a sharp increase in strength and decrease in elongation in all test fuels. No noticeable difference was observed between the test results of the synthetic fuels. The complete test results are shown in Table XVI.



TABLE XVI  
EVALUATION OF SHEET MATERIALS FOLLOWING CONDITIONING  
IN FUEL FOR 7 DAYS AT 140°F (60°C)

<u>MATERIAL</u>	<u>FUEL</u>	<u>TENSILE STRENGTH (psi)</u>	<u>TENSILE STRENGTH (MPa)</u>	<u>ELONG. (%)</u>
Polyethylene	None (controls)	1,800	12.4092	574
	Base JP-4, .1% sulfur	1,220	8.4107	225
	25% arom., 1% sulfur	1,220	8.4107	285
	35% arom., 1% sulfur	1,290	8.89326	350
	45% arom., 1% sulfur	1,190	8.20386	325
	Synthetic JP-4	1,400	9.6516	370
	Synthetic JET-A	1,290	8.89326	240
Nylon 101	None (controls)	8,870	61.14978	103
	Base JP-4, .1% sulfur	11,300	77.9022	17
	25% arom., 1% sulfur	11,600	79.9704	28
	35% arom., 1% sulfur	11,600	79.9704	22
	45% arom., 1% sulfur	11,500	79.281	19
	Synthetic JP-4	12,100	83.4174	21
	Synthetic JET-A	12,100	83.4174	11

Aromatic - Xylene

## SECTION IV

### DISCUSSION OF ALL RESULTS

The overall objectives of the materials evaluation program were to determine the compatibility of existing materials to fuels obtained from shale oil supplies and to determine the compatibility of materials to increasing levels of sulfur and aromatic constituents in aircraft fuels. The materials selected were based on those currently in use in aircraft systems that are or could be exposed to fuels. The materials compatibility test results are summarized in Table XVII. The materials are graded according to the sensitivity to increased aromatic and sulfur levels and to their sensitivity to two fuel systems derived from shale oil. A summary of these results is discussed in the following paragraphs.

#### 1. Effect of Increased Aromatic Content of JP-4 Type Fuels

To determine materials compatibility of the typical aircraft fuel related materials to increasing aromatics, the candidates were exposed to fuels IV, VI, and VIII. These were similar fuels having an increasing level of aromatic content; 25%, 35%, and 45% aromatics, respectively.

The adhesive materials that were cured above room temperature (AF-126, FM-47, and PL-729-3) showed little or no effect as the result of exposure to increasing levels of aromatic constituent in the fuels. The room temperature curing systems (EC-2216 and 828/DTA) showed a loss of shear strength as the aromatic level increased. The fuel tank sealant materials all indicated a loss of some peel strength as a result of increasing aromatic content, but the minimum value recorded was still higher than the minimum specification requirements. The fuel bladder materials, fuel bladder adhesive, groove injection sealants, Marmon clamp seals, electrical

TABLE XVII  
SUMMARY OF ALL THE MATERIALS/FUEL COMPATIBILITY DATA

MATERIAL	SENSITIVITY TO INCREASING AROMATICS		SENSITIVITY TO INCREASING SULFUR CONTENT		SENSITIVITY TO SYNTHETIC JP-4		SENSITIVITY TO SYNTHETIC JET-A	
	None	Slight	Large	Questionable	None	Slight	Large	Questionable
<u>Adhesives</u>								
AP-126	X			X				X
828/DTA		X		X				X <sup>+</sup>
PM-47	X			X				X <sup>+</sup>
PL-729-3	X			X				X
EC-2216		X						
<u>Fuel Tank Sealants</u>								
PS-890								
PR-1422								
PR-1221								
PS-899								
<u>Fuel Bladders</u>								
Buna N Innerliner								
Urethane 80C29								
Pliocel								
Buna N 51956								
<u>Fuel Bladder Adhesive</u>								
EC-678								
<u>Groove Sealants</u>								
PR-703								
DC 94031								
<u>Hannon Clamp Seals</u>								
PMP CL-LGR-60								
PMP AMS-3227								
PMP KK-125								
Kirkill 502-100								

X<sup>+</sup> Indicates an improvement in the material performance over the Base JP-4 fuel

② Indicates that the test results were inconsistent or not expected

TABLE XVII(Continued)

MATERIAL	SENSITIVITY TO INCREASING AROMATICS		SENSITIVITY TO INCREASING SULFUR CONTENT		SENSITIVITY TO SYNTHETIC JP-4		SENSITIVITY TO SYNTHETIC JET-A	
	None	Slight	Large	Questionable	None	Slight	Large	Questionable
<u>O-Ring Materials</u>								
Buna N-Precision 7866		X				X		
Fluorocelastomer-								
Parter V747-75	X					X		
Fluorosilicone-								
Precision 11647	(X)			(X)		(X)		
<u>Fuel Cell Foams</u>								
Hybrid Polyether-Blue	X			X		X		
M11-B-83054A-Red	X			X		X		
<u>Fuel Tank Coatings</u>								
M11-C-27725		X		X		X		
M11-S-4383		(X)				X		
<u>Sheet Materials</u>								
Polyethylene	X			X		X		
Nylon	X			X		X		

X<sup>+</sup> Indicates an improvement in the material performance over the Base JP-4 fuel

X Indicates that the test results were inconsistent or not expected

sheet materials, fuel tank coatings, fuel cell foams, and o-ring materials all showed none or only slight property changes as a result of the increasing aromatic content in the fuel.

## 2. Effect of Increased Sulfur Level on JP-4 Type Fuels

Material sensitivity to increasing sulfur content was determined by comparing the results of the material exposures to fuels I and II. However, many of the materials evaluated were not exposed to fuel II. Since all of the materials were exposed to fuel IV, the comparative evaluations were made between fuels I and IV. The comparisons are only valid, however, when no or only slight property changes were observed because fuel IV not only contains a higher sulfur level than fuel I but also contains higher aromatic levels.

All of the adhesive materials except EC-2216 showed little or no change as a result of the increasing sulfur content in the fuels. The EC-2216 adhesive could possibly be affected by the increased sulfur level; however, it was also affected by the high aromatic content. The material degradation could, therefore, be caused by the high aromatic content and not sulfur related. The fuel tank sealant materials did not appear to be degraded at all by the high sulfur fuel. All of the fuel cell bladder materials except the Buna N innerliner (FT-99) showed only a slight change in performance in the high sulfur fuel. The Buna N innerliner indicated a high permeability rate in the low sulfur fuel but the effect of the aromatic content of the fuel could not be separated. The fuel bladder adhesive, the groove sealants, the Marmon clamp seals, the sheet materials, the fuel tank coatings, the fuel cell foams, and the o-ring materials all

showed little or no additional degradation that would have resulted from higher sulfur exposure.

### 3. The Effects of Synthetic JP-4 Fuel Derived From Shale Oil Deposits

Synthetic JP-4 contains approximately the same aromatic content and slightly less sulfur than the Base JP-4 fuel (fuel I). It does, however, contain considerably higher amounts of fuel bound nitrogen. Nitrogen levels of 10 ppm are commonly found in the Base JP-4 fuel, while typical nitrogen levels of 250 ppm are commonly found in the Synthetic JP-4. Synthetic JET-A is a higher molecular weight (based on distillation range) fuel than JP-4 and is considered similar to JP-8. For these reasons, the synthetic fuels should be treated separately.

The test results showed that the adhesive and fuel tank sealant materials showed only little or no change after exposure to Synthetic JP-4. The fuel cell bladder materials except the FT-99 did not appear to degrade following exposure to the Synthetic JP-4. The Buna N innerliner (FT-99) showed some adverse effects in the Synthetic JP-4 tests. These tests were the permeability test and the seam adhesion test. These are not "all conclusive" type tests and more testing of this material should be conducted to verify these test results.

The fuel bladder adhesive, the groove sealants, the Marmon clamp seals, the electrical sheet materials, the fuel tank coatings, the fuel cell foams, and the o-ring compounds all showed only slight or no degradation as a result of the exposure to Synthetic JP-4.

### 4. The Effects of Synthetic JET-A Fuel Derived From Shale Oil Deposits

The material evaluations of samples exposed to the Synthetic JET-A fuel are based on a comparison between fuels I and IX. As was pointed out

in Section II of this report, Synthetic JET-A was derived from shale oil deposits and is comparable to JP-8. Although the JP-8 and, therefore, the Synthetic JET-A fuels are not directly comparable to JP-4 because of the compositional differences, certain qualitative information relating to materials compatibility can be ascertained.

Generally the performance of the materials evaluated in this program was slightly better in the Synthetic JET-A than in the Base JP-4 fuel. They also seemed to be slightly improved over the Synthetic JP-4. The single significant result of these tests is that the presence of large quantities of fuel bound nitrogen did not apparently degrade these materials. The JET-A fuel had approximately 46 times the amount of fuel bound nitrogen as did the Base JP-4.

Specifically, all of the adhesives, except EC-2216, indicated equivalent behavior or slightly improved performance over the samples aged in the Base JP-4 fuel. The EC-2216 showed a large decrease in shear strength following aging in the Synthetic JET-A. The fuel tank sealant material results were all equivalent to the Base JP-4 results except for the Pro-Seal 899 material which showed a slight improvement in adhesive peel strength. The Buna N innerliner (FT-99) material and the polyurethane 80C29 had their lowest permeability factors following exposure to the Synthetic JET-A. This effect could be related to the fact that the higher weight molecules of the Synthetic JET-A (and JP-8) fuels had more difficulty in penetrating these materials. The seam adhesion test conducted on the Buna N innerliner (FT-99) indicated much poorer adhesion after aging in Synthetic JET-A. The fuel bladder adhesive, the groove sealants, the electrical sheet materials, the fuel cell foams, and the o-ring

materials all indicated none or only slight changes in the results when compared to the Base JP-4. The Buna N fuel tank coating (Mil-S-4383) showed a large increase in hardness following the Synthetic JET-A exposure. Two of the Marmon clamp seal materials showed a slight improvement in behavior over the Base JP-4 fuel.



## SECTION V

### CONCLUSIONS

The specific conclusions reached as a result of this materials evaluation program were based on the test results obtained on each material system. For clarity, each material is discussed separately and is evaluated relative to its ability to resist the fuel environment to which each was exposed.

#### 1. Adhesives

Out of the five adhesive systems tested, the three that cured above room temperature did not indicate any adverse effects from exposure to the high aromatic and sulfur fuels nor from either of the two synthetic fuels. The room temperature curing systems were severely degraded in the higher aromatic fuels and were possibly affected by the higher sulfur fuels. The EC-2216 was also significantly degraded by the Synthetic JET-A.

#### 2. Fuel Tank Sealants

Only slight effects were observed in all the fuel systems. The sealant appeared to be very tolerant of high aromatic fuels, high sulfur fuels, and high nitrogen fuels such as those derived from shale oil deposits. Manganese dioxide cured sealants did indicate some loss of adhesion in fuels doped with xylene. The use of these sealants in the presence of fuels containing large amounts of xylene should be limited.

#### 3. Fuel Bladders

The fuel bladder materials that were evaluated in this program have indicated some degradation in Synthetic JET-A, particularly the Buna N innerliner (FT-99). These effects, however, could be related to the type

of tests conducted, namely permeability and seam adhesion. Since the FT-99 material contains a fabric, it is a more difficult material to seal in the permeability test. It is recommended that these tests be repeated on samples of the Buna N innerliner material and fuel barrier only, without the fabric reinforcement.

#### 4. Fuel Bladder Adhesive

Test results on the fuel bladder adhesive were not at all conclusive. All of the test results obtained on this program were lower than specification values. These data indicated that the adhesive and/or the substrate to which it was bonded were not compatible systems. Based on these test results, it is recommended that the EC-678 adhesive tests be investigated further by ASD/ENF.

#### 5. Groove Injection Sealants

The groove injection sealants evaluated did not appear to be affected by any of the fuels to which they were exposed. The results indicated that only slight changes were evident and that neither the Synthetic JET-A nor the Synthetic JP-4 appreciatively affected the material behavior.

#### 6. Marmon Clamp Seals

The results of Marmon clamp seals tested in this program showed that the Synthetic JP-4 and Synthetic JET-A fuels increased the tensile strength and decreased the elongation of the PMP 24548 compound. This compound, however, lost considerable strength when exposed to all fuel systems, retaining approximately 1/4-1/3 its original strength following aging. Elongations in all fuel systems also decreased by 40%-50% and

volume swells from 93%-156% were recorded. It appears that this material is not a particularly fuel resistant material. Comparisons of test results among the ten fuel systems showed that the compound degraded in the higher aromatic fuels but improved slightly in the synthetic fuels.

The other Marmon clamp materials tested also showed some degradation at the higher aromatic levels. These materials did not indicate any significant change in properties following aging in the synthetic fuels.

#### 7. Electrical Sheet Materials

The test data collected in this program did not indicate any significant losses in ultimate tensile strength as a result of the fuel exposures. These included the higher aromatic fuels, the high sulfur fuels, and the two synthetic fuels.

#### 8. Fuel Tank Coatings

The two fuel tank coating materials tested were a Buna N coating and a polyurethane coating. Both showed some slight softening in the higher aromatic fuels. Both coatings also showed a large increase in hardness after exposure to Synthetic JET-A. No change in hardness was observed after the Synthetic JP-4 exposure.

#### 9. Fuel Cell Foams

The hybrid polyether and the Mil-B-83054A polyurethane foams did not show any significant effect resulting from exposure to the test fuels. These foams appeared to be very stable in all of the test fuels and should be suitable for use in the higher aromatic and higher sulfur fuels.

#### 10. O-Ring Materials

The Buna N, fluoroelastomer, and fluorosilicone o-ring compounds were exposed to all ten fuels. The Buna N seemed to be slightly affected by

increasing aromatic and sulfur levels and slightly sensitive to Synthetic JP-4 and Synthetic JET-A.

The fluoroelastomer and the fluorosilicone compounds did not appear to be influenced by increasing aromatic and sulfur levels but did appear to be slightly degraded in Synthetic JET-A. No significant effect was observed after the exposure of these compounds to Synthetic JP-4. The test results of the fluorosilicone compound, particularly the ultimate tensile strength and elongation, were very low, although consistent. These included the control test results which were only about two-thirds of the expected value. The hardness of the control samples was also low.

## SECTION VI

### RECOMMENDATIONS

Based on the results of these tests it could be said that most materials are reasonably tolerant of increasing aromatic levels up to 35%. The maximum sulfur level tested in this program was 1% total sulfur and, again, most materials were tolerant of that level. It was observed in this effort that it was difficult in most cases to separate the effect of the higher sulfur level fuels from the higher aromatic level fuels. In future programs, it is recommended that the test materials be exposed to an additional fuel that would enable the sulfur effect to be more easily determined. An example would be that all materials be exposed to fuel III (Base JP-4/0.1% sulfur/25% aromatics) as well as fuel IV (Base JP-4/1.0% sulfur/25% aromatics).

It is also recommended that future programs include an additional fuel to serve as a base fuel for the Synthetic JET-A fuel. The addition of a JP-8 type fuel as a base fuel would serve as an effective means of comparison for the Synthetic JET-A.

Specific recommendations concerning the use of several of the materials evaluated in this program are identified in the following paragraphs.

a. It is recommended that the room temperature curing adhesive systems used in this program not be used in either a highly aromatic fuel or in those typically represented by Synthetic JET-A.

b. The test results on the fuel bladder materials and the fuel bladder adhesive were difficult to interpret due to the influence of the fabric reinforcement on the overall bladder material. It is recommended

that these tests be repeated on the Buna N 51956 and the Buna N FT-99 without the fabric reinforcement to confirm the results obtained with the composite structure.

c. The fluorosilicone o-ring materials evaluated in this program seemed to be very low in properties and had some inconsistent swell data. It is recommended that these data be repeated to verify the trends observed in this program.

d. Since manganese dioxide cured fuel tank sealants were observed to degrade in high xylene containing fuels, the extent to which xylene occurs in JP type fuels should be investigated and should possibly be included in referee type test fuels such as Jet Reference Fluid (JRF).

## APPENDIX

### BACKGROUND INFORMATION - FUEL PROPERTIES VS AVAILABILITY

#### 1. Introduction

Grade JP-4 is the primary operational fuel used by the Air Force. The requirements for Grade JP-4, as specified by Mil-T-5624J, were established to provide both wide availability and satisfactory performance. Current fuel shortages are leading to consideration of adjusting requirements in order to further increased availability. A review of the history of the development of JP-4 is appropriate to indicate how these requirements were established and to provide guidance for any efforts directed towards adjusting the requirements.

History <sup>(1)</sup> of gas turbine engine fuel dates to 1944 with the introduction of JP-1. This -76°F freeze point fuel, having a 300°F to 500°F boiling range, could not be produced in sufficient quantities to meet military requirements. In an effort to increase availability, a wider cut fuel, JP-2, was authorized in 1945. JP-2 was used only for experimental purposes as viscosity restrictions limited its production. The availability problems posed by JP-1 and JP-2 resulted in the adoption of JP-3 in 1947. JP-3 was produced by blending gasoline with kerosene. It was found that while fuel requirements could be met, the relatively high Reid vapor pressure of 7 psi caused excessive losses in the order of 20 percent <sup>(2)</sup> by venting of liquid and vapor in high rate of climb aircraft and at high altitudes. For these reasons a specification for JP-4, which essentially is a low vapor pressure JP-3, was issued in 1951 and at present is the standard USAF jet fuel.

While there have been refinements to the fuel specification to keep pace with engine developments, JP-4 has basically maintained the critical properties first specified to insure availability and to fulfill aircraft operational performance requirements. JP-4 is a wide cut mixture of heavy gasoline and kerosene with an average 140°F to 460°F boiling range. It possesses a maximum freeze point of -72°F and a Reid vapor pressure of 2 to 3 psi at 100°F, a compromise volatility that assures availability with reduced vaporization loss. Related to the volatility is an expected low flash point of approximately -20°F and an explosive range from approximately -20°F to 70°F under equilibrium conditions.

The Air Force continues to be interested in converting from Grade JP-4 to Grade JP-8. Grade JP-8 is a 105°F flash point and -58°F freezing point kerosene fuel which essentially is the same as commercial airline grade Jet A-1 fuel. One reason for this interest is that the Southeast Asia Conflict demonstrated that aircraft survivability and vulnerability needed to be improved and Grade JP-8 had potential for yielding benefits in this area. Another reason is that new systems such as the B-1 and F-15 use fuel extensively for cooling and low volatility JP-8 is easier to manage than high volatility JP-4 in the aircraft fuel systems.

Middle distillate fuels such as kerosene or Grade JP-8 are limited in supply as a result of the energy crisis and as a result of increased demand for this type of fuel. Consequently, conversion to Grade JP-8 has been postponed until availability improves.

Since the Grade JP-4 specification as now written provides a compromise between availability and aircraft performance requirements,



drastic changes in allowable limits for properties are not envisioned. There may be some latitude in selected properties where modest adjustments will provide appreciable gains in availability. This remains to be evaluated.

## 2. Substantiation of the Requirements

### a. Volatility

Volatility is controlled by distillation range, vapor pressure, and freezing point. The requirements for Grade JP-4 are:

20% distilled at not over 290°F

50% distilled at not over 380°F

90% distilled at not over 470°F

Vapor pressure at 100°F between 2.0 - 3.0 psi

Freezing point not higher than -72°F

Volatility requirements are established to assure easy ignition, efficient burning, and wide availability.

The distillation requirements mean that at least 20% of the fuel volume will evaporate when fuel temperature reaches 290°F, etc. More than 20% may be evaporated by the time the fuel reaches 290°F, etc. These requirements force volatility in the direction of gasoline rather than kerosene or, in other words, in the direction of greatest availability.

The distillation requirement then is not particularly restrictive. The 20% requirement along with the vapor pressure requirement does assure the presence of light hydrocarbons which favors ignition. The 50% and 90% requirements prevent substantial quantities of heavy hydrocarbon which would be difficult to vaporize and burn cleanly in turbine engines.

The vapor pressure requirement controls the amount of light hydrocarbons in the fuel blend and the initial boiling point of the fuel. The 3 psi upper limit prevents the fuel from boiling at altitudes up to 40,000 feet (where the ambient pressure is 3 psi) which is above the service ceiling of most aircraft. Boiling would result in excessive loss of fuel through tank vents and would cause fuel line cavitation and starvation of fuel to the engine with subsequent flameout.

While the freezing point requirement primarily relates to low temperature operations, it also determines the percentage of heavy hydrocarbons in the fuel blend. Kerosene fuel availability is much more sensitive to the freezing point requirement than JP-4. However, JP-4 final boiling points rarely exceed 530°F and the mean of production is 460°F, so freezing point apparently excludes higher boiling components although not specifically excluded by the requirements.

b. Hydrocarbon Composition

Aromatics are limited to 25 volume percent. Naphthalenes (bicyclic aromatics) are implicitly limited to below 3% by Luminometer number. The relative amounts of paraffins and naphthenes (cyclic paraffins) are not controlled.

Aromatics affect combustion properties and the design of elastomeric seals (o-rings) and, consequently, their level must be controlled.

Combustion properties of fuels are related primarily to hydrogen content, assuming adjustments are made for variations in density and viscosity. As hydrogen content decreases, soot deposits, exhaust smoke, and thermal radiation increase. Soot deposits and thermal radiation can increase to the point that combustor liner burnout will occur. The relationship between hydrogen content and combustor performance has been extensively substantiated. (3), (4), (5), (6), (7)

Environmental and tactical considerations that have evolved in recent years are added reasons for controlling exhaust smoke. This, in turn, requires control of hydrogen content.<sup>(8)</sup> & <sup>(9)</sup> It is interesting to note that the tactical disadvantage of leaving an obvious smoke trail behind a military aircraft was recognized in 1954<sup>(4)</sup> but did not receive major attention until the Southeast Asia conflict occurred.

The order of decreasing hydrogen content, and correspondingly, increasing smoking and heat radiation for fuel constituents are:

paraffins

naphthenes (cyclic paraffins)

olefins

aromatics

naphthalenes (bicyclic aromatics)

Elastomeric o-rings are formulated and designed to swell (dilate) and provide an effective compressive seal when exposed to a given range of aromatics.<sup>(10),(11),(12)</sup> If aromatics are too high, swelling is excessive and the seal can erupt from its cavity. If aromatics are too low, swelling is not sufficient to effect a seal and leakage occurs. Cycling from a high aromatic fuel to a very low aromatic fuel results in permanent shrinkage to below seated dimensions, also causing leakage. The o-ring doesn't recover when subsequently exposed to high aromatic fuel and has to be replaced. These problems substantiate control of aromatics from a fuel system material standpoint.

Olefins, particularly terminal olefins (double bond at end of molecule) are controlled because they are unstable<sup>(13)</sup>, i.e. they polymerize (combine with each other) and oxidize easily resulting in gum formation.

Fuel is maintained in dormant storage for long periods (War Readiness Material) consequently stability is essential. Fuel also is used as a coolant in aircraft fuel systems so thermal stability, also affected by olefins, is critical in order to avoid deposition of gums and carbonaceous materials in heat exchangers, manifold lines, and nozzles.

c. Sulfur

Sulfur is present in fuels as organic sulfides and as mercaptan sulfur. Total sulfur is limited to 0.4 weight percent and mercaptan sulfur is limited to 0.001 weight percent.

Mercaptan sulfur, if not controlled, damages both o-rings and integral fuel tank sealants.<sup>(14)</sup> Sealant attack is promoted by cadmium plated fasteners which still exist in KC-135 and early model B-52 aircraft.

Organic sulfides have been limited because they corrode fuel wetted components and are involved in hot section corrosion. Fuel system corrosion is less critical and probably was a factor when copper was used in fuel systems. Use of copper has been discontinued because copper migrates to the fuel and levels as low as 20 parts per billion cause serious degradation of thermal stability.<sup>(15)</sup>

The mechanisms of hot corrosion of turbine blades is unresolved but it is generally agreed that existence of sodium sulfate on the turbine blades is a prerequisite for sulfidation type corrosion. It follows that presence of sodium is a prerequisite for sulfidation. The amount of sodium chloride in the air in a marine environment is much less than that required to convert 0.4 weight percent sulfur to sodium sulfate. It also

should be noted that sea water already contains appreciable amounts of sodium sulfate, although there is some doubt that it condenses on turbine blades at normal turbine temperatures. It has been observed that the degree of corrosion does not change until the sulfur level drops below that required to convert all of the sodium chloride (in air containing sea water) to sodium sulfate.<sup>(16)</sup> & <sup>(17)</sup>

There is some doubt then that corrosion is a reason for controlling sulfur content in light of current knowledge.

Sulfur also degrades thermal stability and forms undesirable sulfur dioxide emissions. Although the original premises for controlling total sulfur may not still be valid, low total sulfur requirements will be maintained for the above reasons.

#### d. Freezing Point

The freezing point of JP-4 is not allowed to be higher than -72°F. This requirement has been established to insure that fuel freezing does not occur in aircraft tanks during long flights and in the refueling boom during aerial refueling. Observed fuel temperatures<sup>(18), (19), (20)</sup> as given below indicate that some, but not all, aircraft could operate with higher freezing points. Use of multiple fuels introduces logistic problems and increases fuel cost. However, a study<sup>(21)</sup> on conversion to Grade JP-8 (-58°F freezing point) indicates that freezing point can be increased without creating any major problems. It would be necessary to continue to service certain aircraft with -72°F freezing point JP-4.

<u>Aircraft and Flight</u>	<u>Ambient Temperature °F</u>	<u>Ambient Temperature °F</u>
B-57, 7 hours	-118	-67
707, 36 flights	-70	-34
KC-135, 8 hours	-73	-40

e. Thermal Stability

It is required that the fuel not form lacquer or tar type deposits or form carbonaceous solid particles when heated to 300°F and when in contact with a metal surface where the surface temperature is 500°F. Conditions for laboratory tests have been established to represent fuel and metal temperatures that exist in aircraft heat exchangers, engine fuel manifolds, and engine fuel nozzles.

The thermal stability requirement implicitly limits the amount of olefins, sulfur, trace materials, and unstable compounds in aviation turbine fuels. The requirement influences the degree of finishing processing such as hydrotreating and filtration required to meet the specification.

Engine fuel manifolds are necessarily in intimate contact with the hot section of the engine and, of course, fuel nozzles are located at the dome of combustors. Heating of the fuel cannot be avoided. Most turbine engine designs result in fuel temperatures reaching 325°F at the nozzle exits.

Recent aircraft such as the F-15 and B-1 use fuel extensively for cooling airframe components. Thermal stability then is becoming progressively more critical as fuel reaches the engines at about 200°F. Fuel also is used to cool the engine lubricant.

If thermal stability is not controlled, heat exchanger fouling and overheating occurs, nozzles become blocked, and fuel controls may malfunction resulting in excessive maintenance and degraded engine performance.

f. Other Requirements

Cooper strip corrosion, total acid number, water reaction, water separator index, and particulate matter requirements eliminate corrosive trace contamination, presence of surfactants which deactivate filter/separators, carry-over of refinery processing materials, and presence of solids which damage fuel lubricated components and fuel controls.

Fuel system icing inhibitor is required to prevent ice blockage of aircraft fuel system screens and attendant fuel starvation of the engines. Undissolved water can be minimized in fuel delivered to aircraft but water still accumulates in undrainable tank areas by condensation from air during vent breathing and dissolution from fuel as the fuel cools during flight. Fuel normally contains 100 parts per million dissolved water. The inhibitor also inhibits microbiological growth in aircraft tanks. This problem still plagues commercial airline operators who do not use the inhibitor.

Corrosion inhibitor is required in JP-4 to insure that the fuel is an adequate lubricant. The fuel serves as a lubricant in boost pump bearings, engine hydraulic systems, fuel controls, and engine fuel pumps.

Density and viscosity are controlled to preclude wide variations that would cause difficulties in fuel pumping, metering, and nozzle spray patterns.

### 3. Impact of Changing the Requirements

It is apparent from the previous comments that there are limits on how far requirements can be changed. There are some new problems that would arise as a consequence of changing requirements that may not be obvious in the prior discussion.

Increasing vapor pressure, for instance, also will increase raw vapor emissions from ground fuel handling facilities and during refueling operations. Controlling raw vapor emissions is difficult at 3 psi vapor pressure, the current JP-4 limit.

Increasing volatility will increase the demand for naphtha, the upper gasoline and lower JP-4 boiling range components. Naphtha is a demand for synthetic natural gas production, petrochemical feed stock, burning fuel, and reforming stock for low lead gasoline production.<sup>(22)</sup> Raising vapor pressures and lowering initial boiling points will deplete stocks used for other products.

Raising the freezing point above the current  $-72^{\circ}\text{F}$  will permit use of higher boiling components. Unburned hydrocarbon emissions may increase as final boiling point increases. Environmental considerations may override availability factors making it necessary to establish a final boiling point requirement. It has already been stated that components derived from the middle distillate range are in short supply so availability may not increase by raising freezing point.

Grade JP-4 is allowed to contain 25% aromatics but averages 11%. Consideration of aromatic levels above 25% would not appear to have a general impact on availability although some localized gains may be



realized. Increased usage of low lead and unleaded motor gasoline is increasing demands for aromatics. Aromatic gasolines, while not particularly responsive to tetraethyl lead, already have high octane numbers without tetraethyl lead added. Aromatics also are used for petrochemicals.

Grade JP-4 is allowed to contain 0.4 wt% total sulfur but averages 0.05 wt%. Grades JET-A and JET-A-1 are allowed to contain 0.3 wt% total sulfur but also average 0.05 wt%. Raising the allowable limits on sulfur will increase sulfur oxide emissions which will be environmentally objectionable. One benefit is to permit increased refining of sour crudes (high sulfur) which would increase availability. A detriment is that raising the limit allows a higher processing rate which may not increase availability and result only in poorly refined fuels at the same cost.

Increasing aviation turbine fuel availability by adjustment of properties will have the overall effect of reducing stocks used for other products. It is desired that the effect be to increase the number of crude sources and not interfere with other products. This tends to be an idealized outlook as all available crude is being processed and refineries are operating at full capacity yet shortages exist for all products.

It is necessary to quantify the impact of changing requirements in order to establish what quality of fuel can be accepted under emergency conditions and what individual properties can be waived under normal conditions. As examples, JP-4 has been offered with a 3.3 psi vapor pressure in one case and with 0.003 mercaptan sulfur in a separate case.

Assessment of the impact of changing requirements would enable clear decisions relative to acceptance of product which is off-specification on one property. This contrasts with an approach of adjusting all specification properties at one time.

## REFERENCES

1. Botteri, B. P., et al, A Review and Analysis of the Safety of Jet Fuel, AF Aero Propulsion Lab, Wright-Patterson AFB, OH 45433, AFAPL-TR-66-9, March 1966.
  2. Peterson, I. C., "Fuel Conditioning of Gas Turbine JP-3 Fuel," AIA letter report, 25 May 1950.
  3. Garner, C. M., Full-Scale Testing of Jet Engine Fuels, Power Plant Laboratory Report TSEPP-531-472, 23 July 1947.
  4. Anon., Survey of Jet Fuel Performance Data, Standard Oil Co., (Indiana) memorandum M54-146, 8 March 1954.
  5. Johnson, J. H., Full Scale Engine Tests of Special Fuels A and B, Power Plant Laboratory, Wright Air Development Center, Wright-Patterson AFB, OH 45433, WADC-TN-55-741, October 1955.
  6. Johnson, J. H., Full Scale Engine Tests of Special Fuel F54-19, Power Plant Laboratory, Wright Air Development Center, Wright-Patterson AFB, OH 45433, WADC-TN-56-330, November 1955.
  7. Horstman, W. W., and Jackson, J. L., Combustion Characteristics of Special Hydrocarbon Jet Fuels, Shell Oil Co., ASD-TDR-62-682, July 1962.
  8. Schirmer, R. M., Specification of Jet Fuel Hydrogen Content for Control of Combustion Cleanliness, Phillips Petroleum Co., Report 3195-62R, June 1962.
  9. Schirmer, R. M., Effect of Fuel Composition on Particulate Emissions From Gas Turbine Engines, 1971 General Motors Research Symposium on Emissions from Continuous Combustion Systems, Warren, MI, September 1971.
  10. Anon., "Study of the Effects of High Aromatic Fuels on Elastomers," Thiokol Chemical Corp., Polysulfide Rubber Bulletin, January 1959.
  11. Testroet, F., Effect of High Aromatic Content Fuels on Elastomer Vulcanizates, Rock Island Arsenal, Report No. 59-851, 25 March 1959.
- Headrick, R. E., Investigation for a Standard Hydrocarbon Test Fuel for Rubber Component Qualifications Evaluation, Technical Memorandum 63-63-18, March 1963.
- "Aviation Fuels," G. T. Foulis & Co. Ltd., 1970.

REFERENCES (Continued)

14. Miller, L. O., Effect of Mercaptan Compounds in JP-4 on Rubber Materials at High Temperatures, Wright Air Development Center, Wright-Patterson AFB, OH 45433, WADC-TN-56-347, June 1956.
15. Schenk, L. W., Investigation of the Effects of Trace Metals on the Thermal Stability of JP-7 Fuels, Southwest Research Institute, AFAPL-TR-71-98, December 1971.
16. Schirmer, R. M., Effect of Sulfur in JP-5 Fuel on Hot Corrosion of Turbine Blade Materials in Marine Environment, Phillips Petroleum report No. 5903-71, January 1971.
17. Stringer, J., "Hot Corrosion of Gas Turbines," University of Liverpool, England, May 1973.
18. Morgan, J. T., Advanced Hydrocarbon Fuel Tests, Aeronautical Systems Division Report No. ASTDN 66-8, June 1966.
19. Anon., "Summary of Minimum Fuel Temperatures - TransAtlantic Boeing 707-331 Flights," February 1962. Unpublished data.
20. French, E. J., RB-57F Fuel Environmental Test, San Antonio Air Material Area Report SAOQT-TR-66-1, September 1966.
21. Clodfelter, R. G., "Assessment of JP-8 as a Replacement Fuel for the Air Force Standard Jet Fuel JP-4," Unpublished.
22. Riley, P. W., "JP-8 Availability and Price," Department of the Interior letter report, October 1971.